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EFFECTS OF SKEW ANGLE ON SIMPLE SPAN BRIDGE DECKS UNDER SIMULATED TRUCK LOADING

BY

PAUL M. KUZIO

Thesis
K96

EFFECTS OF SKEW ANGLE ON SIMPLE SPAN BRIDGE DECKS UNDER SIMULATED TRUCK LOADING

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PAUL M. KUZIO

A REPORT PRESENTED TO THE GRADUATE COMMITTEE
OF THE DEPARTMENT OF CIVIL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

SUMMER 1984

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CHAPTER 1

INTRODUCTION

1.1 Overview

Modern bridge designs often include decks whose spans are at a skew angle to their supports for economic or aesthetic considerations. The behavior of these structures is largely dependent upon a variety of factors such as the angle of skew, direction of reinforcement, aspect ratio, orthotropic stiffeners and types of loading. The effects of these and other factors on the mechanics of deformation may be interdependent, thus requiring a study including variation of parameters. This report will examine the effects of skew angle on major principal moments of free spans under simulated truck loading. Orthogonal and skewed reinforcement will also be discussed.

The finite element approach has been selected as the method of analysis. A mesh size study is undertaken in Chapter 2 to examine the effects of singularities caused by concentrated loads. GTSTRUDL [5] software is used for the stiffness analysis on a VAX 11-750 digital computer. A service load simulator program is written in FORTRAN-77 (Appendix A) and is run semi-interactively with GTSTRUDL to incrementally adjust the truck position. The parameter studies are discussed in Chapter 3. Here the major principal moment at center span is plotted against the location of the truck for various angles of deck skew. The moment reductions which are found for increased angles of skew do not necessarily allow for a reduction in reinforcing steel. The angles at

which the major principal moments intersect the steel plays an important role in the efficiency of resisting flexure. This relationship is discussed in Chapter 4.

1.2 The Nature of Plate Bending

An orthogonal isotropic plate subjected to transverse loading deflects according to the differential equation [18]

$$\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = - q/D \qquad (1)$$

In the case of a simple span such as a bridge deck of Figure 1.1(a) the solution to (1) must also satisfy the boundary conditions

$$\left.\begin{array}{lr} w = 0 & \text{(Zero Deflection)} \\ \left(\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right) = 0 & \text{(Zero Moment)} \end{array}\right\} \text{Along Simple Supports} \qquad \begin{array}{r}(2)\\(3)\end{array}$$

and

$$\left.\begin{array}{lr} \left(\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right) = 0 & \text{(Zero Moment)} \\ \left(\frac{\partial^3 w}{\partial x^3} + (2 - \nu)\frac{\partial^3 w}{\partial x\, \partial y^2}\right) = 0 & \text{(Zero Shear)} \end{array}\right\} \text{Along Free Edges} \qquad \begin{array}{r}(4)\\(5)\end{array}$$

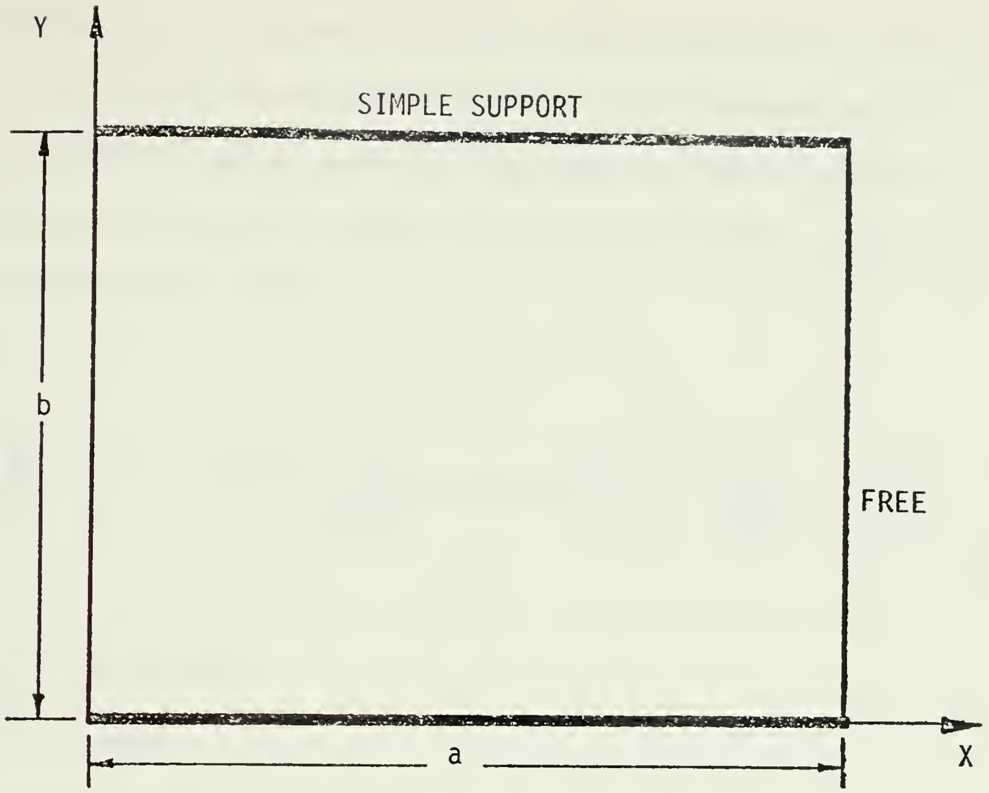
where: w = displacement

x,y = cartesian coordinates

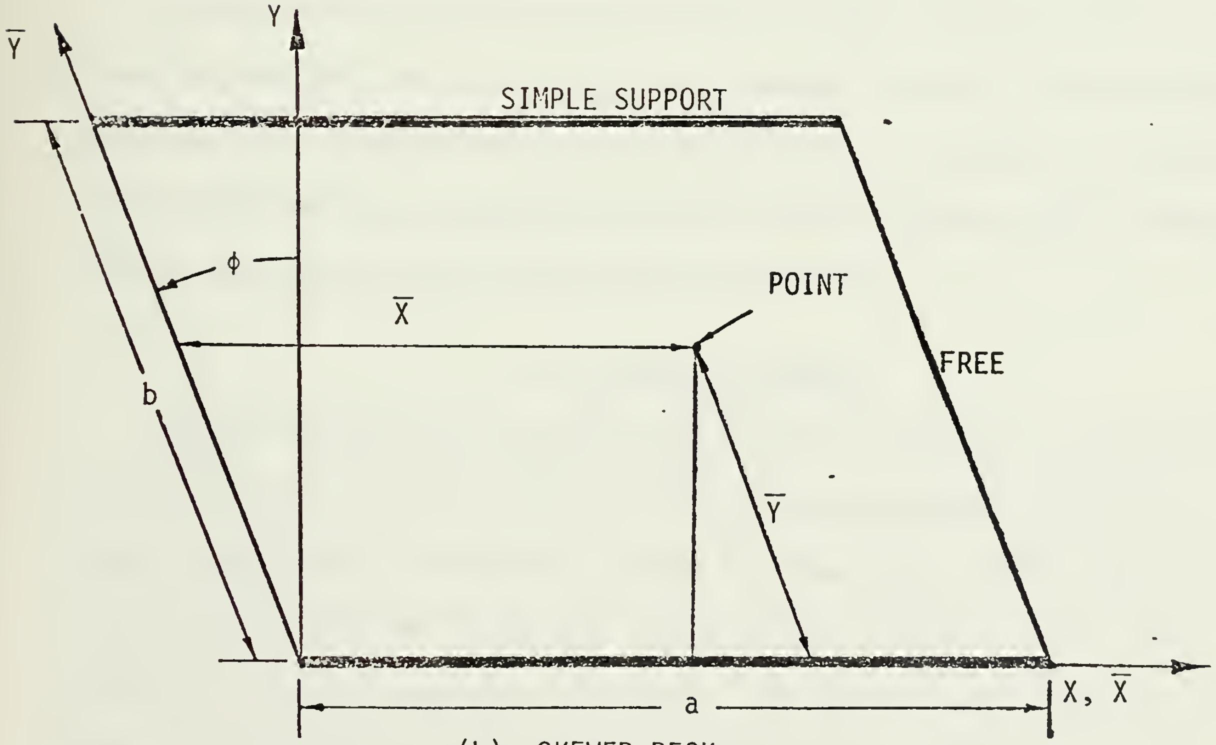
ν = poisson's ratio

q = loading function

D = isotropic stiffness



(a) ORTHOGONAL DECK



(b) SKEWED DECK

FIGURE 1.1 FREE SPANS

These equations can be solved for many loading conditions by the use of Fourier series. For skewed plate analysis, the introduction of an oblique coordinate system, such as that shown in Figure 1.1(b) is required for the analysis. After transformation of the Laplacian, equation (1) becomes [17]

$$\frac{D}{\cos^4\phi}\left\{\frac{\partial^4 w}{\partial \bar{x}^4} + 2(1 + 2\sin^2\phi)\frac{\partial^4 w}{\partial \bar{x}^2 \partial \bar{y}^2} + 4\sin\phi\left(\frac{\partial^4 w}{\partial \bar{x}^3 \partial \bar{y}} + \frac{\partial^4 w}{\partial \bar{x} \partial \bar{y}^3}\right) + \frac{\partial^4 w}{\partial \bar{y}^4}\right\} = p(\bar{x},\bar{y}) \quad (6)$$

where: $\bar{x} = x + y \tan\phi$

$\bar{y} = y \sec\phi$

ϕ = deck angle of skew

$p(\bar{x}, \bar{y})$ = transformed loading function

Solutions to (6) are difficult even for simple loading cases and are therefore not well suited to extensive parameter studies, although Kennedy [10] has been successful with series solutions on a computer. Analytical methods have also been applied by Krettner [12] and Lardy [13]. Energy methods have been used by Guzman and Luisoni [6].

1.3 Numerical Methods

Several researchers have been successful in analysis of skew slabs by the finite difference [8], [9] and finite element methods [1], [15]. The growing popularity of numerical methods for skew slab analysis may be attributed to both the inadequacy of analytical solutions and to the advances in today's computer technology. The latter, particularly, has allowed for extensive use of numerical methods in applied mechanics. Several package programs such as STRUDL [14] are available to the public and have become a widely accepted method for analysis, design and research.

The Finite Element Method was selected for this study using GTSTRUDL [5] software on a VAX 11-750 computer. The finite element approach breaks up or "discretizes" the structure to be analyzed into a network of constituent elements. In plate bending each of these elements is usually allowed three types of displacements or "degrees of freedom" at each corner node (two orthogonal rotations and one transverse displacement). A mathematical function is assumed to describe the displacement variation between the nodes. Then, the stiffness properties of the individual elements can be developed in matrix form. If compatability between the adjacent elements is satisfied then the solution obtained should "converge" as the number of elements is increased. Here compatibility refers to the fact that the pieces must fit together and that all adjoining elements at similar nodes must have corresponding degrees of freedom. Strictly, compatibility is not completely satisfied for the Bending Plate Parallelogram (BPP) element which is used in this study. Zienkiewicz [20] shows it is not possible for a simple polynomial expression to ensure full compatibility when only one displacement and two rotations are prescribed at the nodes. However, experience [20] with the BPP element shows that it "converges" to a good engineering approximation in most practical cases.

Although many different types of elements may be used in discretizing a structure, the procedure is fundamentally the same. The material properties and boundary conditions are first defined for the problem. The element mesh is then selected and the structure stiffness matrix is formed from the known element stiffness matrix. Matrix algegra can then be used to solve the equation relating displacement, moment, strain and stress. Several texts (such as [3] and [20]) are available which detail the finite element process and give many diverse applications.

CHAPTER 2

MESH SIZE STUDY

2.1 Introduction

The first step in analyzing a structure by the finite element method is selecting a mesh size and pattern. The mesh is a very important feature of the study and must be selected with care. In this study the following aspects of mesh size, type and pattern were considered:

1. Accuracy of results
2. Economy of computer time
3. Ease of comparison of results at varied angles of skew
4. Assurance of conforming to the criterion of non-distorted elements.

GTSTRUDL provides for a wide range of elements suitable for this study. The element type chosen is the Bending Plate Parallelogram (BPP) which is very well suited to skew plate analysis. The BPP uses a fourth order transverse displacement expansion and uses three degrees of freedom (one displacement and two rotations) at each corner node. At 90 degrees the BPP is equivalent to the more familiar Bending Plate Rectangle (BPR). The element is not considered distorted unless it is skewed to an interior acute angle of less than 30 degrees. Consequently, it can be used for deck skew angles of up to 60 degrees.

This study will model the deck as a free span between simple supports. The thickness is held constant at 18 inches and the moments X and Y are released at the joints along the supported edges. Before proceeding further it must be pointed out that there are two ways to geometrically "skew" a plate from a rectangle to a parallelogram, both of which are used extensively in the literature. The first way is to keep all edges the same length and allow the supports to move closer together as the angle of skew is increased. This is illustrated in Figure 2.1(b). The other widely used convention is to maintain a constant distance between the supports and allowing the free edge to "stretch" as a skew angle is increased. Figure 2.1(c) illustrates this convention. This study will adopt the first convention for the simple reason that a thin strip taken parallel to the inclined side will approximate the span of an equivalent simple beam, the length of which will be held constant as the deck skew angle is varied. Moreover, the reinforcement is generally laid parallel to the deck edges as well and holding these lengths constant may be a more realistic approach. Thus for all the examples in which the results are compared between the skewed deck and an orthogonal deck, the geometries shown in Figure 2.1(a) and 2.1(b) are implied.

2.2 Determination of Element Size

Before skew angle can be investigated, the proper element size must be determined by a convergence study of the solution of rectangular deck of dimensions similar to those used in practice. Hereafter, the term "span" will refer to the inclined distance (skewed dimension) between supports. Also the ratio of width to span will be abbreviated WSR where

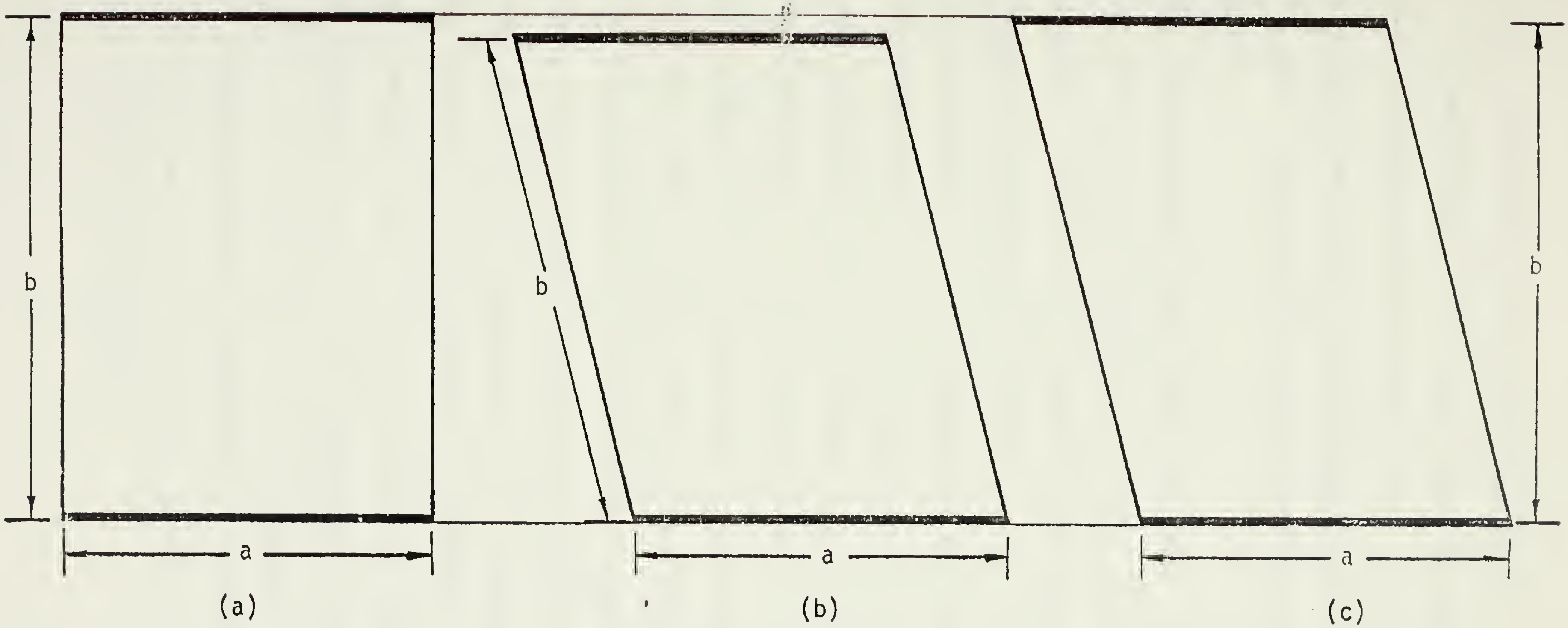
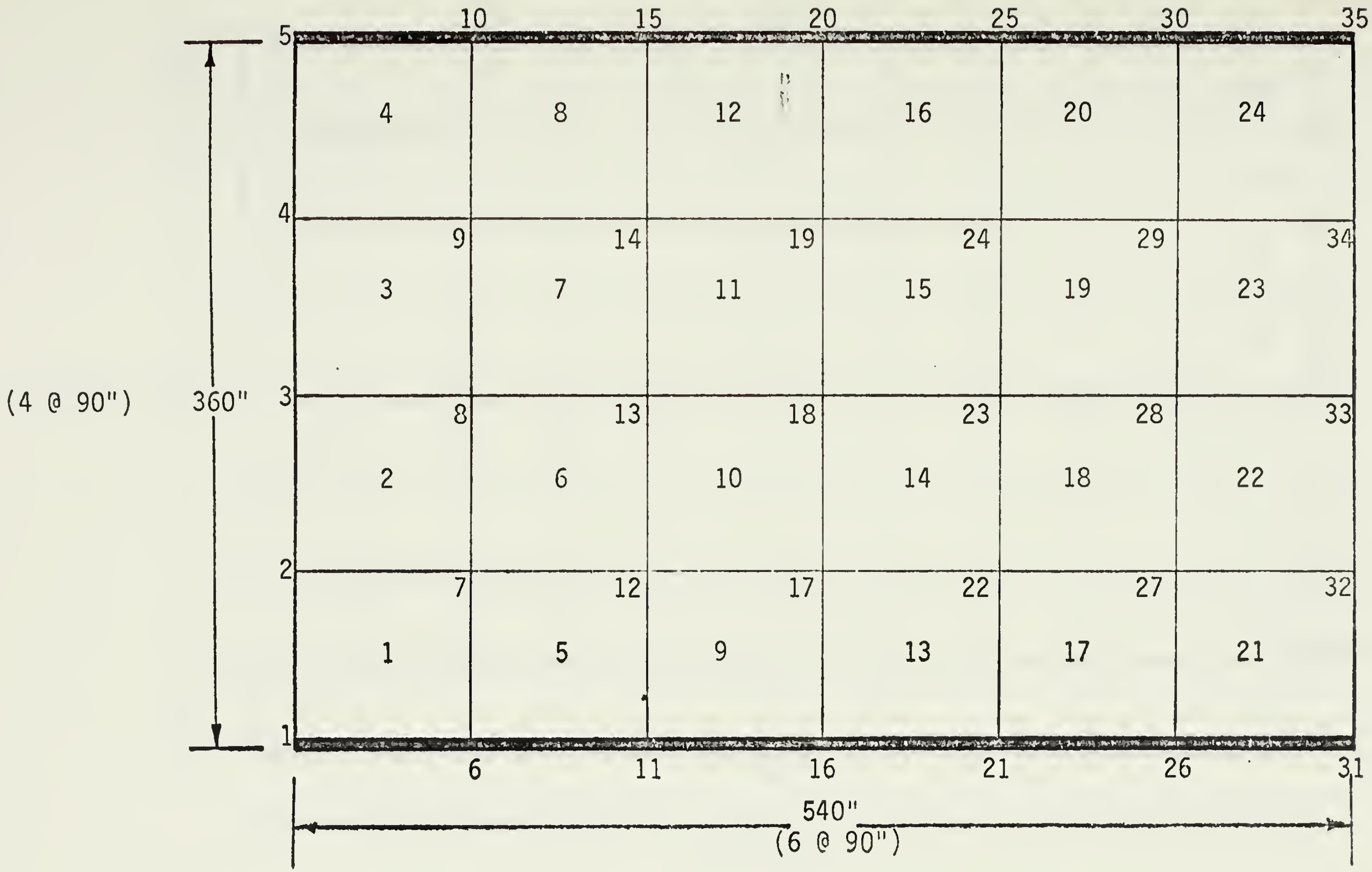


FIGURE 2.1 TWO WAYS TO "SKEW" A PLATE. METHOD (b) WILL BE USED IN THIS REPORT

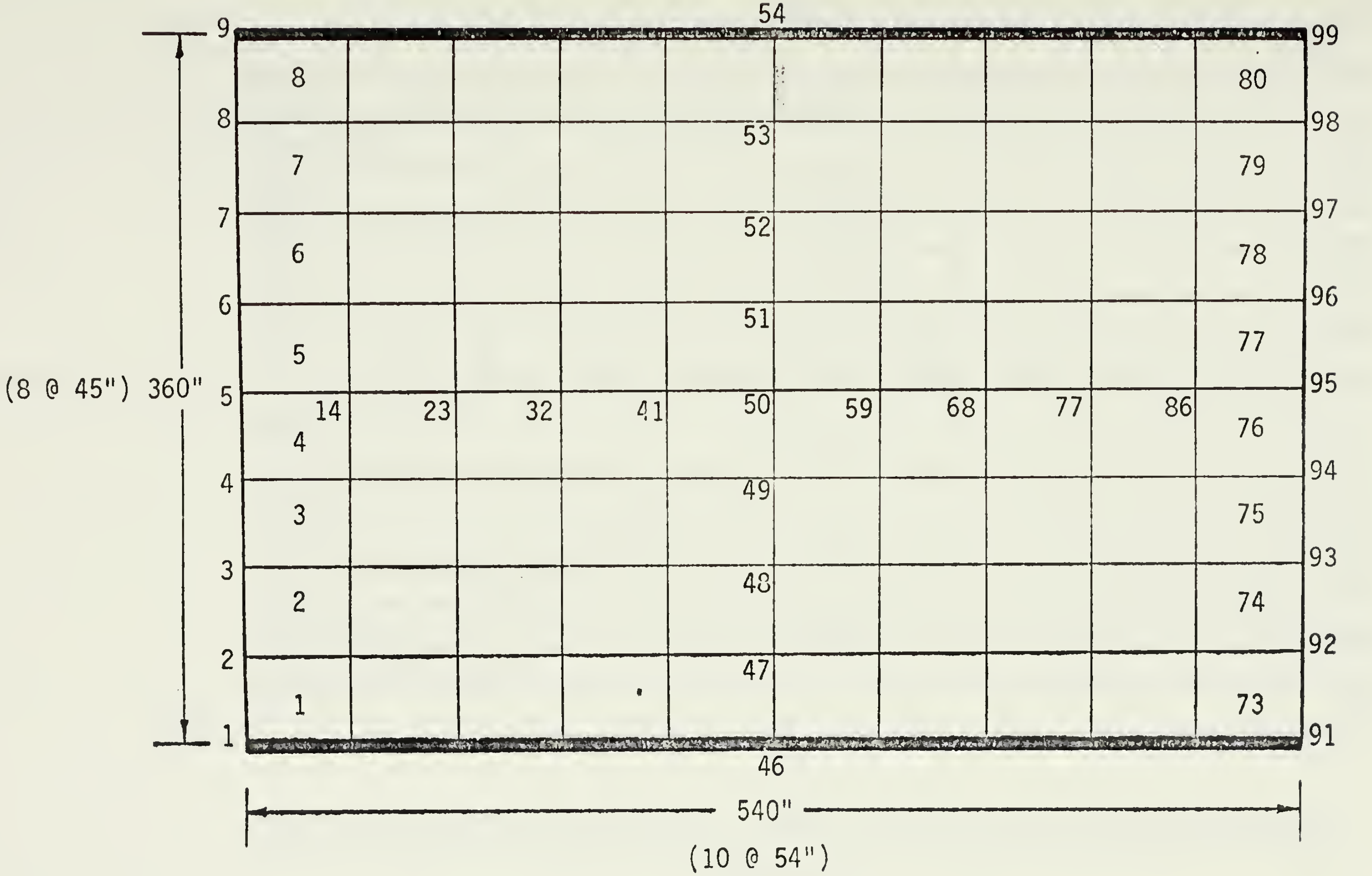
the width is the distance along the supported edge. The WSR parameter will be varied throughout the study in much the same way as the aspect ratio is in orthogonal plate analysis. The span length chosen for the mesh size study was 30 feet and the supported edge length 45 feet (WSR = 1.50). Three mesh sizes were investigated based on these dimensions.

The first mesh was called "RIGHT" (Figure 2.2) and consisted of 24 elements (4 in the span direction and 6 along the supports) each 90 inches square. The idea of the study is to start with this coarse mesh and compare the results to increasingly more refined meshes. However, since the comparisons are made based upon a 10 kip concentrated central load, the finer meshes will not be approaching a finite value (because, as is well known from thin plate theory, a point load produces infinite stress). Therefore it is anticipated that the true solution will lie somewhere between the first course mesh run and one of the finer modifications. A more accurate finite element analysis can be made using the load area equal to the tire contact (imprint) area, and comparisons can be made with the "point load" mesh runs to determine which will give the best approximation. The second mesh was titled "RTFINE" (Figure 2.3) and was given 8 span elements each 45" and 10 transverse elements each 54". For the third run these 80 elements were bisected bilaterally to give a 320 element mesh called "RTEXFINE" (Figure 2.4). As expected the values for the central span moment under the load increased in the two successive finer meshes (see Figure 2.5). The values went from 3.25 k-in/in (RIGHT) to 3.86 k-in/in (RTFINE) to 4.48 k-in/in (RTEXFINE).



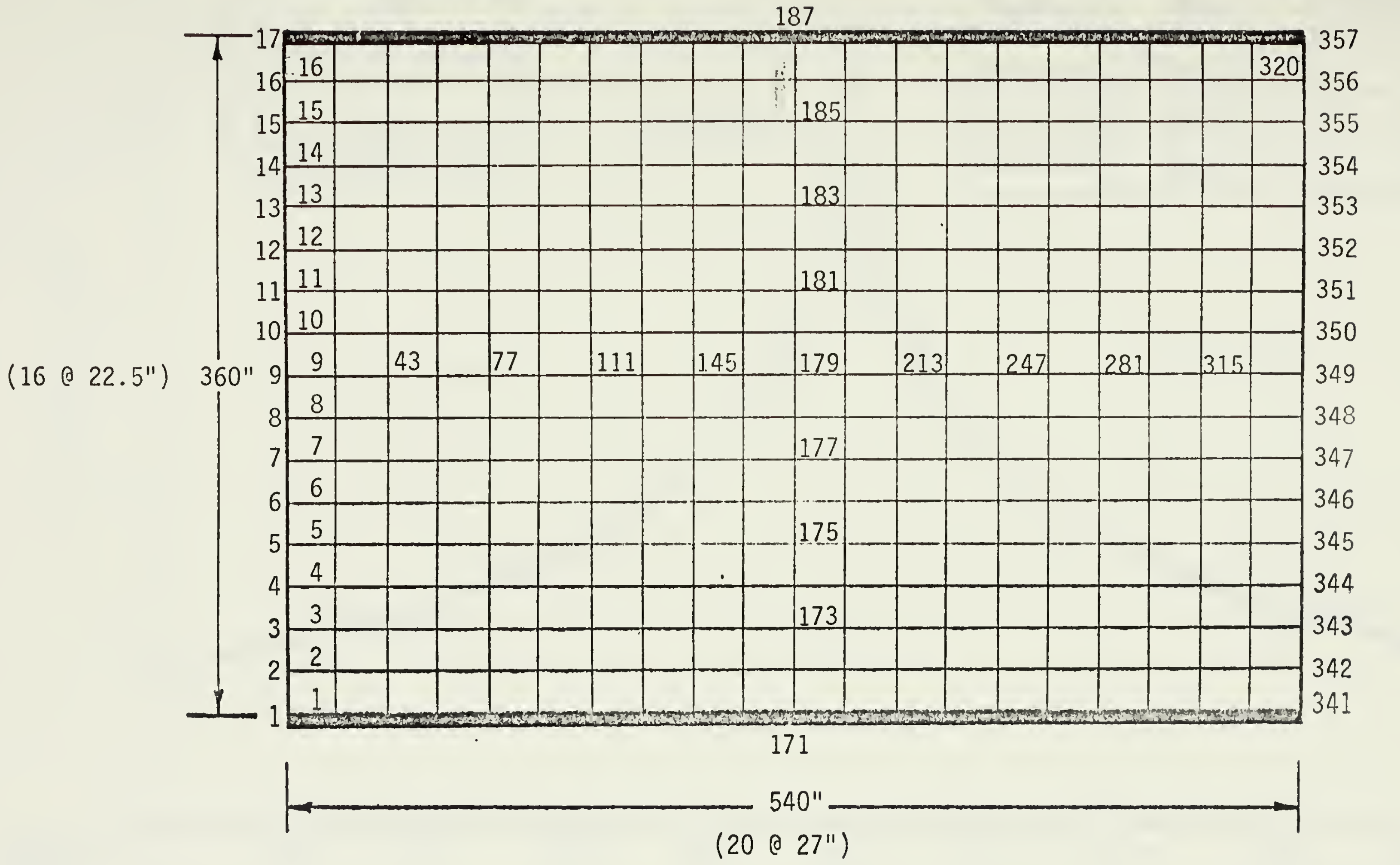
THICKNESS = 18"

FIGURE 2.2 MESH "RIGHT"



THICKNESS = 18"

FIGURE 2.3 MESH "RTFINE"



THICKNESS = 18"

FIGURE 2.4 MESH "RTEXFINE"

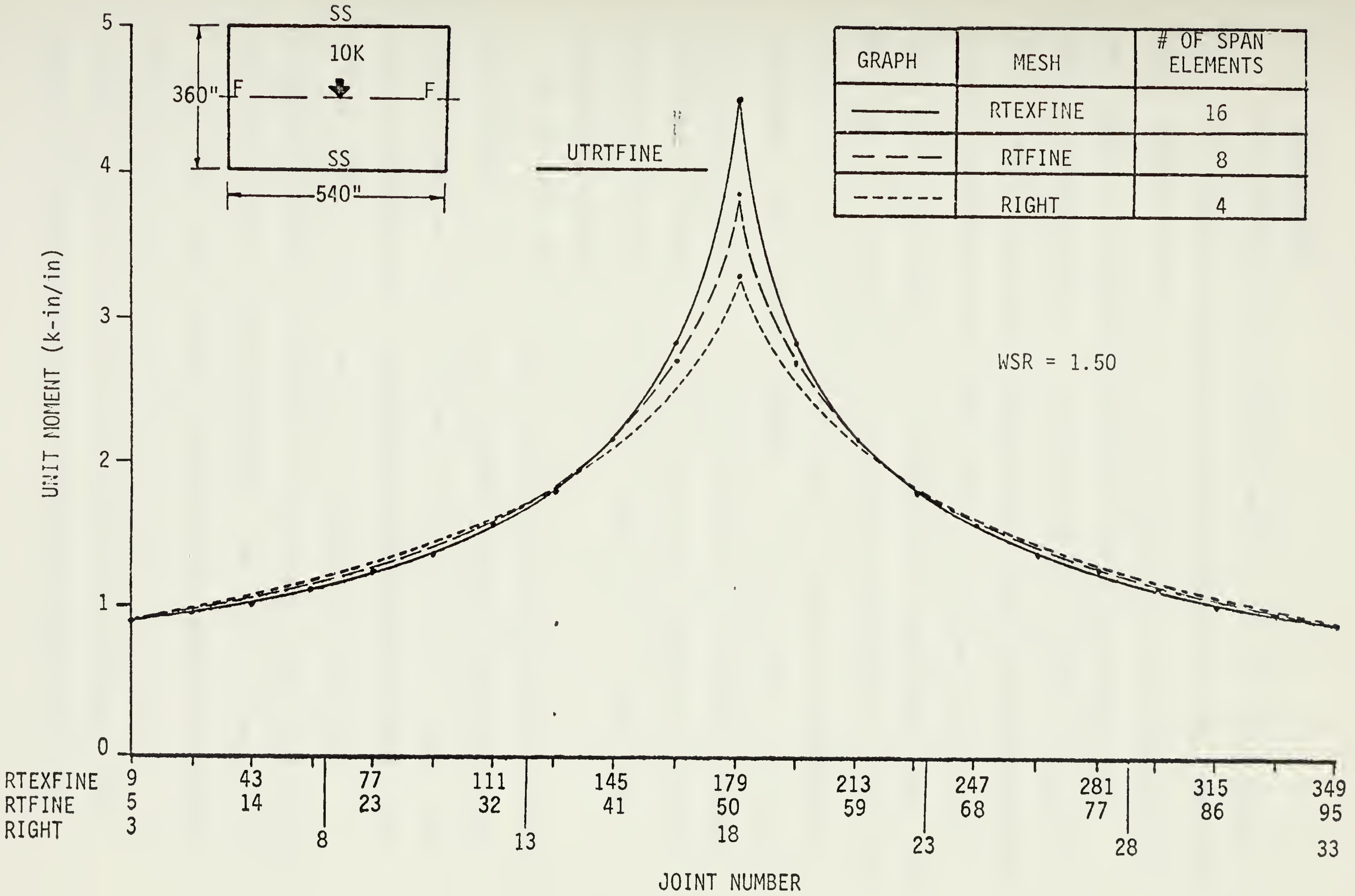


FIGURE 2.5 TRANSVERSE MAJOR PRINCIPAL MOMENT ALONG MIDSPAN

2.2.1 Convergence

The problem now is to determine which (if any) of these results are close to the moment found under a more realistic tire load. The double wheel contact area of a water tanker truck was studied in Reference 4. The dimensions are approximated here to a rectangle of 10" x 24". Interior element loads (i.e., concentrated loads within the boundaries of an element) can be approximated by placing the force upon imaginary stringers parallel to the element edges and using the resultant reactions at the nodal points as a new collection of equivalent loads. This technique will be used later in the program SKEW LOADER as a method for finding statically equivalent nodal loads for any truck position on a skewed deck. This technique, however, is not applicable at this point as the objective here is to avoid the singularities caused by concentrated loads altogther. Therefore a more exact approach is required before we can obtain a solid basis for comparison in choosing the appropriate mesh size.

Since GTSTRUDL will accept uniformly distributed loads only over an entire element (i.e., no partial element loading), an extremely fine localized mesh has to be developed to surround this tire load. Extra care must be taken here to ensure that compatibility conditions are satisfied between element and that no elements are distorted. Distortion is defined in GTSTRUDL as having aspect ratios greater than 2.0 or acute angles less than 30 degrees. Rectangular elements cannot be used in this localized mesh as compatibility cannot be maintained without highly distorting element aspect ratios. Therefore, a triangular pattern was carefully assembled for the localized mesh (Figure 2.6) using GTSTRUDL element Bending Plate Hybrid Triangle

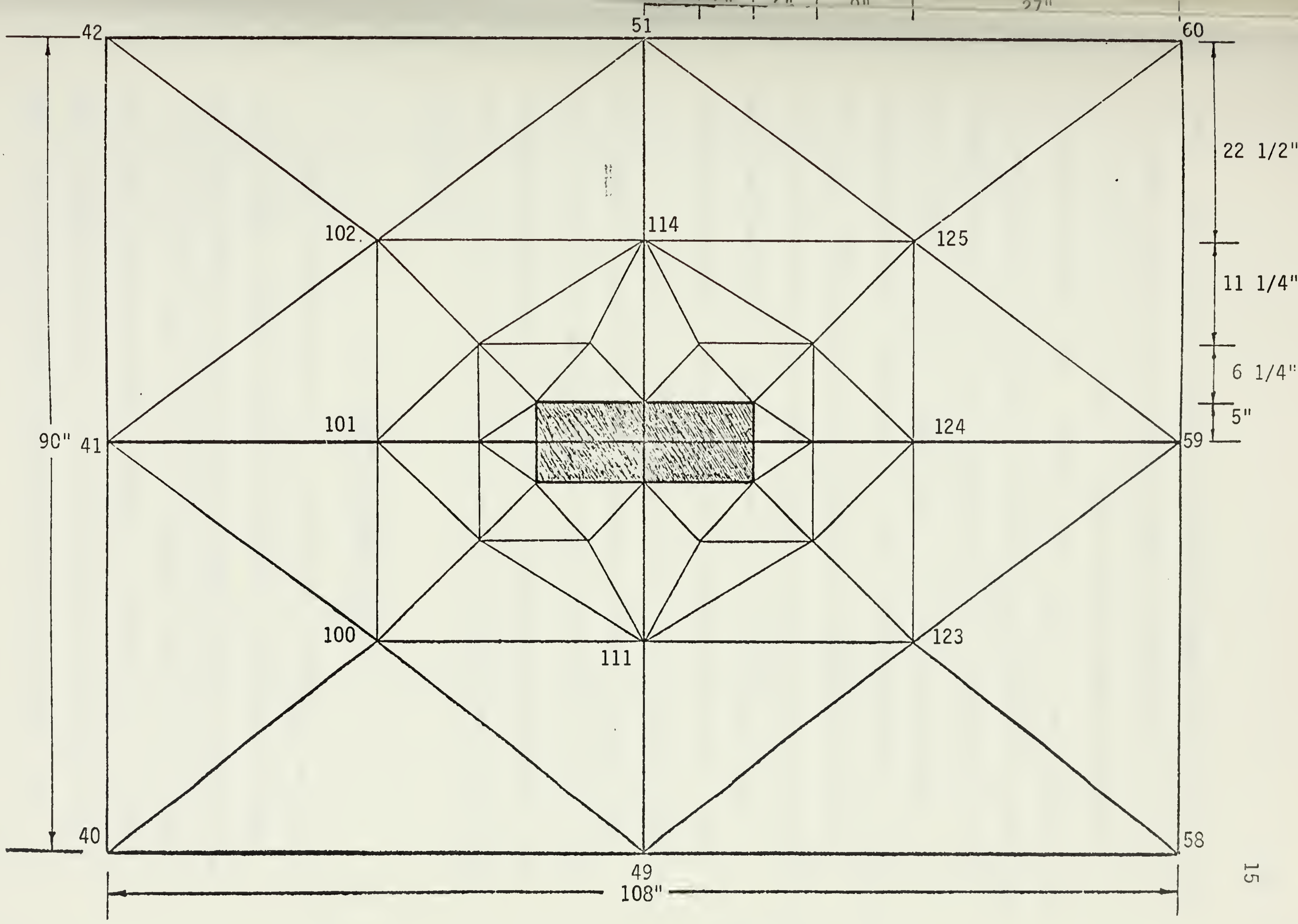


FIGURE 2.6 LOCALIZED TRIANGULAR MESH (CENTER IS JOINT #50)

(BPHT). Due to the high degree of correlation between the data obtained from three different meshes (RIGHT, RTFINE and RTEXFINE) for areas not in the vicinity of the load, the RTFINE mesh was chosen to house the localized triangular mesh. In other words, Figure 2.6 was inserted into the hatched portion of Figure 2.7. The central portion of the localized triangular mesh contains four rectangles each 5" x 12" which are loaded with a uniform pressure of 0.04167 ksi. This modified system is therefore statically equivalent to a central 10 kip concentrated load on the plate. This mesh, called UTRTFINE, gave a central span moment of 4.107 k-in/in which falls slightly above the moment given by the RTFINE mesh (see Figure 2.8). Since the moment of the RTFINE mesh with a concentrated central 10 kip load is only 6.2% lower than this "exact" value, it is considered that the RTFINE mesh will be accurate enough for the purpose of investigating the variation in moment with deck skew angle. The cost in computer time for using the RTEXFINE mesh would be increased exponentially as the number of elements are quadrupled, and would as equally overestimate the moment as the RTFINE mesh would underestimate it.

2.3 Effect of Aspect Ratio

Before the RTFINE mesh could be selected as the proper mesh size for the study, one more check had to be made. If the results showed substantial changes in accuracy when the aspect ratio of the plate was varied, then this would indicate that the mesh size used in the study would have to vary as the WSR is changed. A similar run was therefore made to compare the output of the RTFINE mesh with a more exact value where the aspect ratio has been reduced from 1.50 to 0.60. The

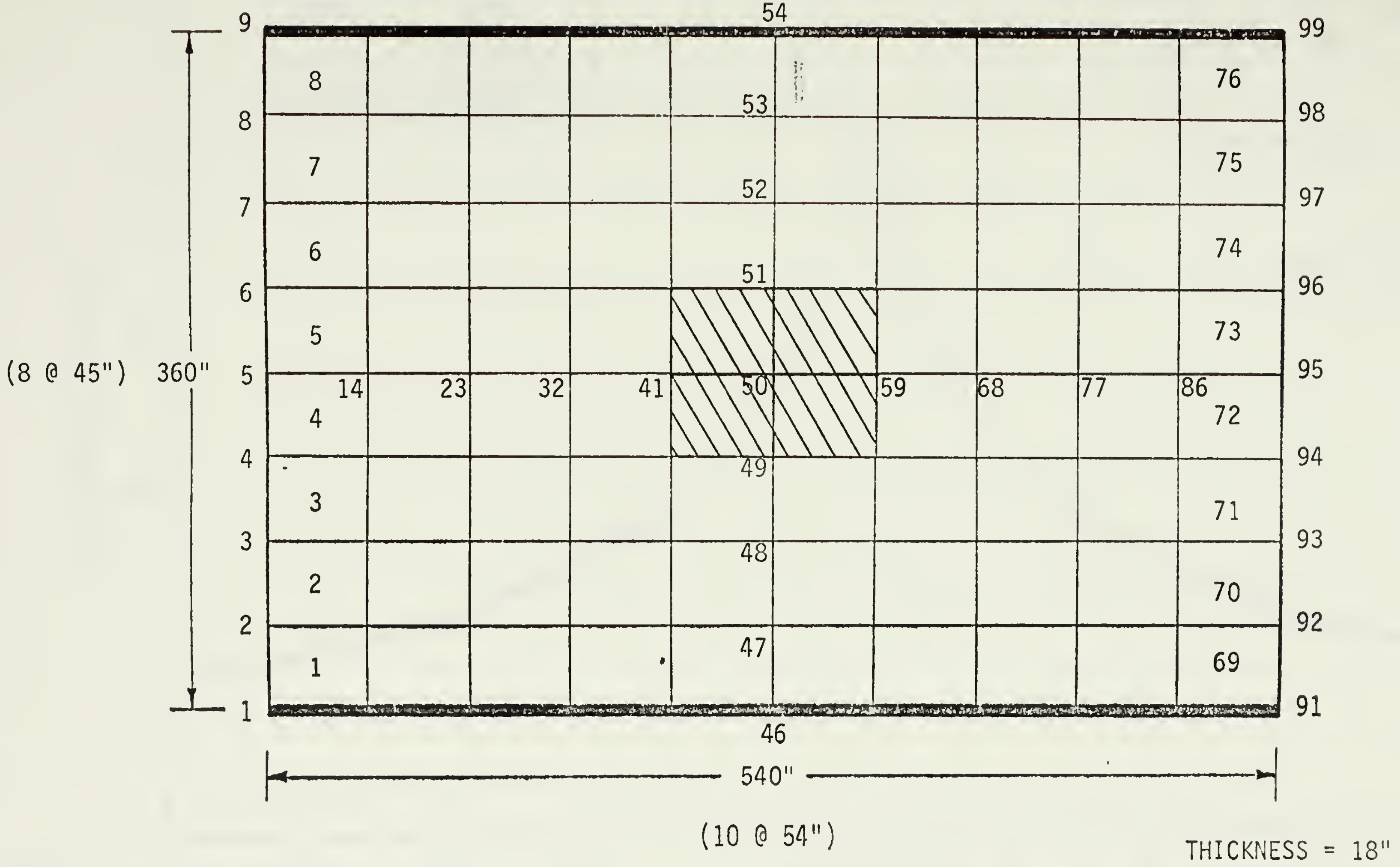


FIGURE 2.7 MESH "UTRTFINE"

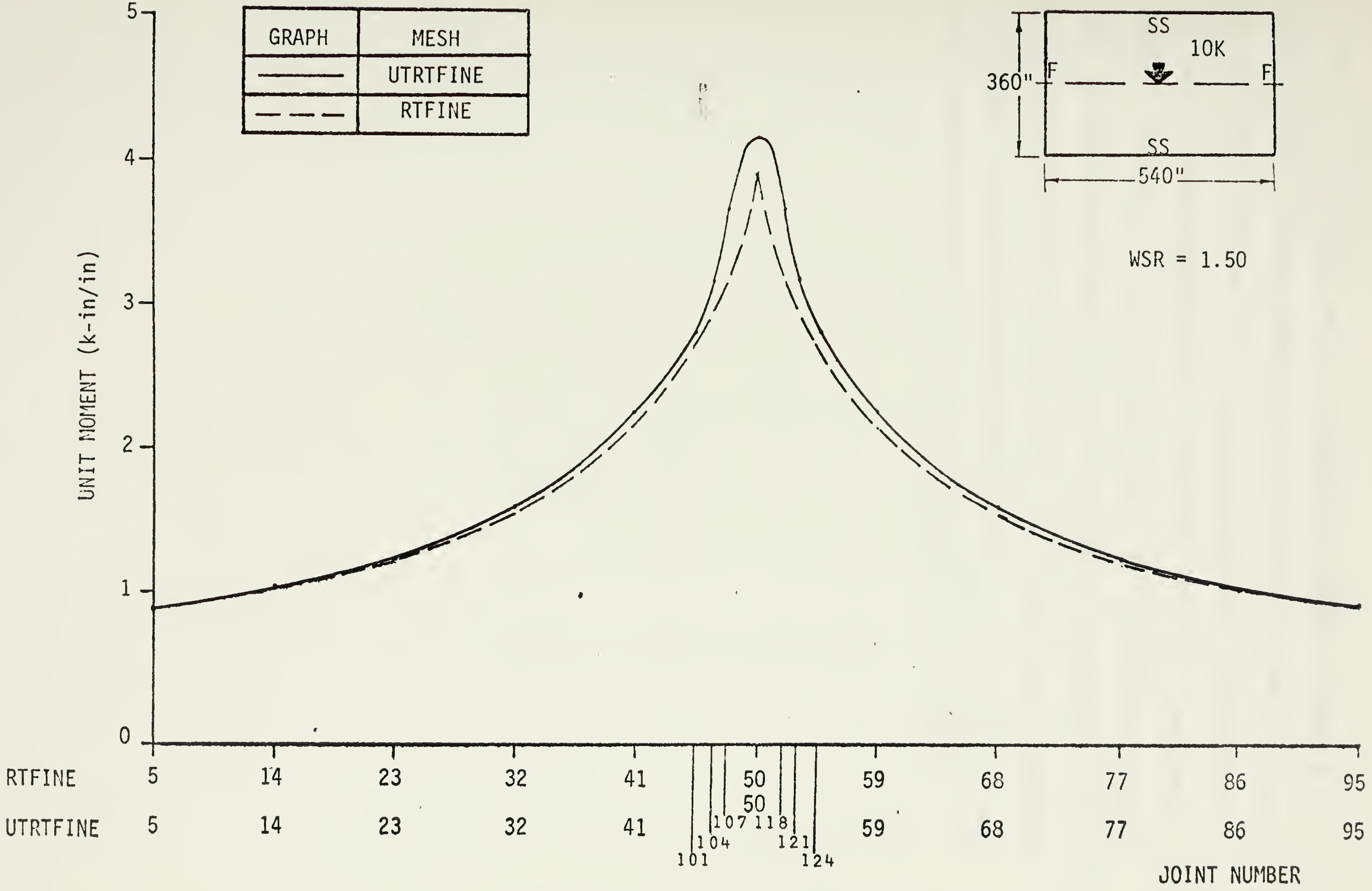
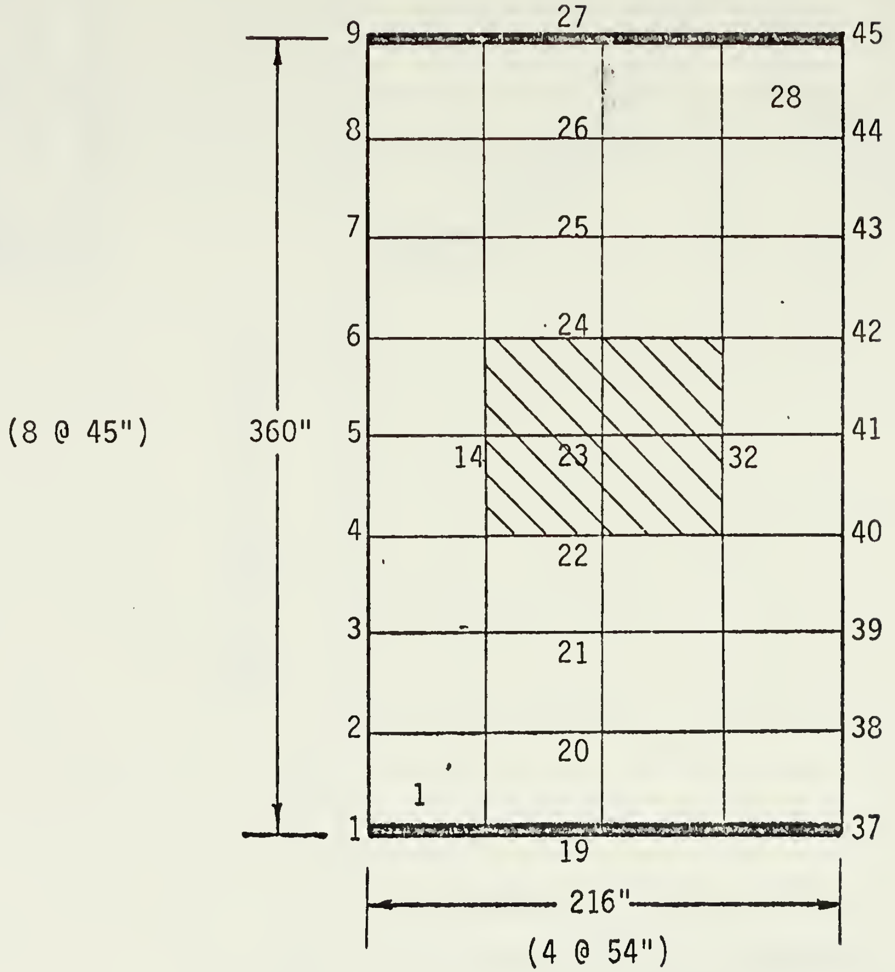


FIGURE 2.8 COMPARISON OF RTFINE AND UTRFINE

respective meshes were renamed RTFINE060 and UTWSR060 (Figure 2.9). The mesh of Figure 2.6 was renumbered to be housed in the mesh of Figure 2.9 as shown and comparisons were again made between the central span moments given by the two outputs. The results showed no substantial change in behavior at the new aspect ratio. The UTWSR060 (more exact) gave a central span moment of 5.69 k-in/in while the RTFINE060 gave 5.44 k-in/in, or 4.3% less (see Figure 2.10). The RTFINE mesh is therefore considered a satisfactory approximation to the true deck behavior and will be used as the basis for investigating the effect of skew.



$\frac{W}{S} = 0.60$

THICKNESS = 18"

FIGURE 2.9 MESH (a) RTFINE060 (WITHOUT INSERT)
(b) UTWSR060 (WITH INSERT)

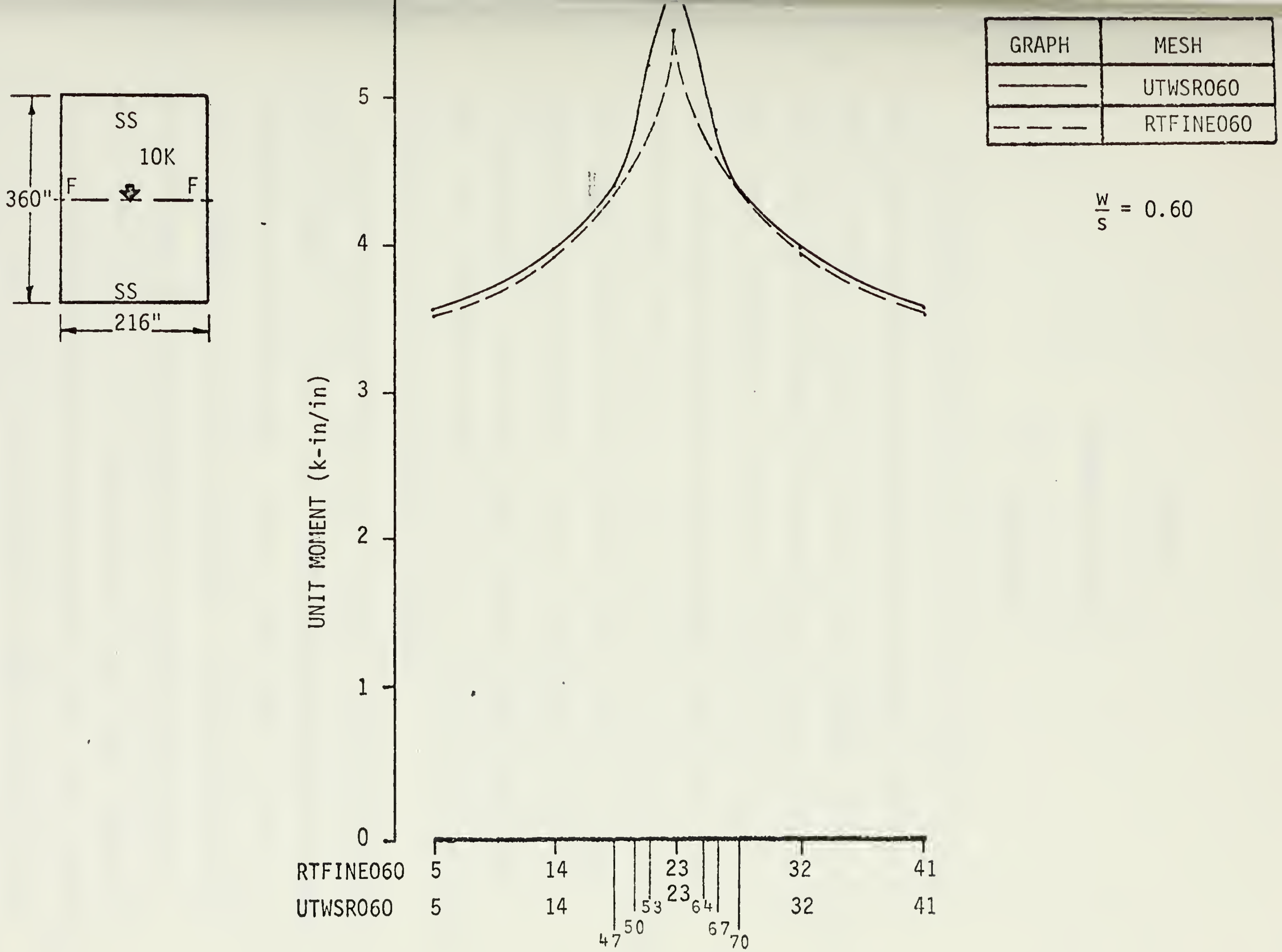


FIGURE 2.10 COMPARISON OF RTFINE AND UTWSR060

CHAPTER 3

PARAMETER STUDIES

3.1 Introduction

Now that the mesh RTFINE has been selected as a guide for the element size, the effect of skew angle can be studied. In order to obtain a realistic evaluation of the variation in maximum moments, the loading used must correspond to the dimensions and axle weights of an actual truck. Furthermore, a consistent convention must be used to establish the truck position for varying angles of deck skew. The principal moment at key points of the slab will be evaluated by GTSTRUDL finite element analysis for each position of the truck as it moves incrementally across the span. Then the corresponding results for different angles of skew can be compared when plotted on the same graph. Since the WSR may affect the moment variation as the skew angle is changed, it too will be treated as a parameter.

Figure 3.1 shows the models to be studied. The principal moments will be computed for WSR's of 1.50, 1.00 and 0.75 while the skew angle is changed from 0 to 40 degrees. For the case of WSR = 1.00 (rhombus), skew of 20 degrees will also be investigated. In all cases the truck will move along the inclined centerline as measured from support to support. In the case of the rhombus, the effects of edge loading will also be examined as the truck is moved across the span inset at 48" from the left free edge. In all cases the deck is simply supported at the top and bottom edges and free along the left and right edges. This will be the conventional orientation of the deck throughout this report.

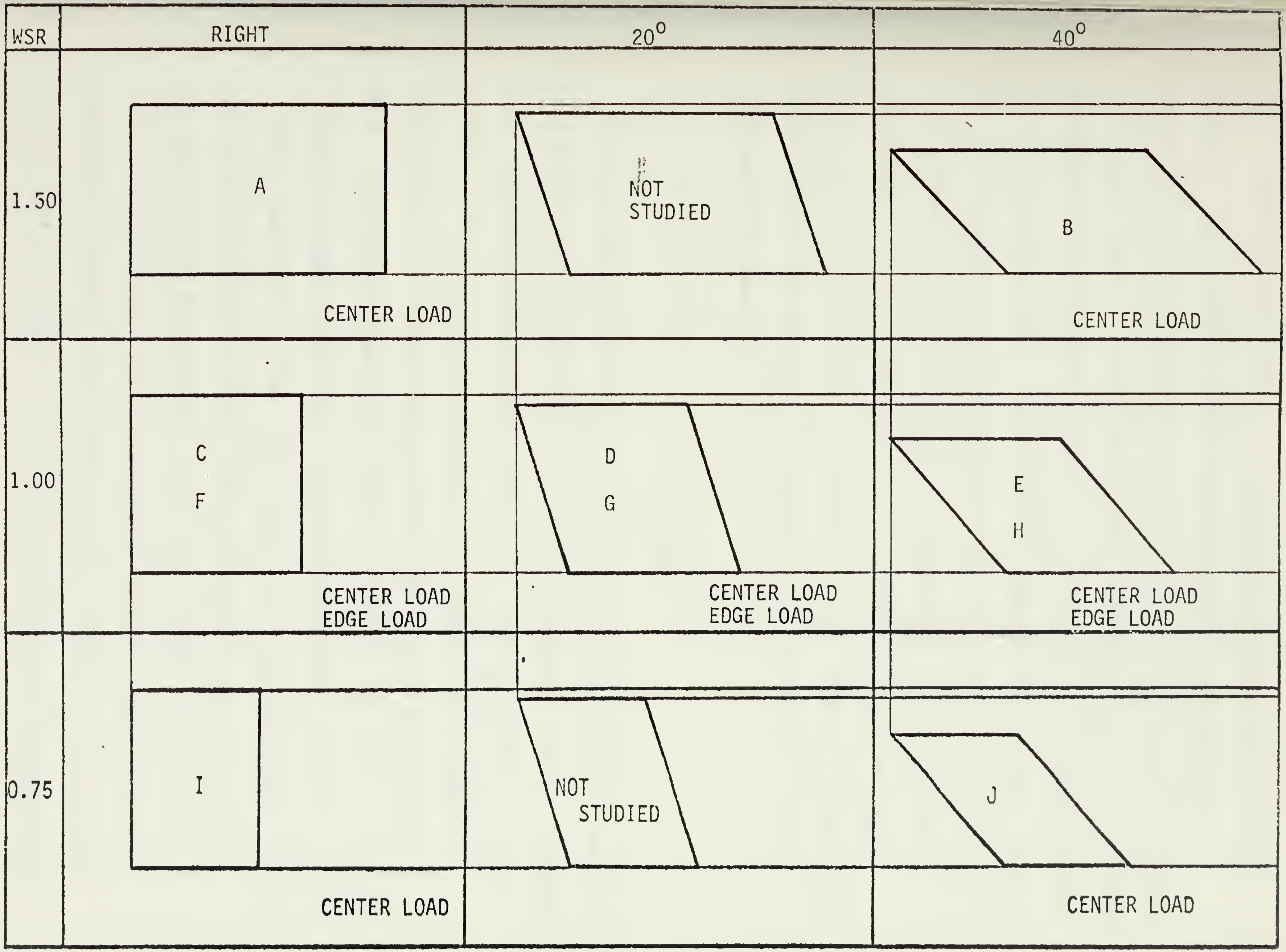


FIGURE 3.1 PARAMETER STUDIES

The truck chosen for the investigation was the 70 kip FDOT-SU4 (Figure 3.2). The span dimension of the deck was selected for convenience to be 32 feet in order that 8 span elements of 48" (Figure 3.3) may be used as in the RTFINE deck. The RTFINE actually used 8 span elements of 45", though the element study showed the difference should be of negligible order. The transverse dimensions were varied from 48 to 32 to 24 feet to allow the WSR to change from 1.50 to 1.00 to 0.75, respectively. Transverse element dimension was chosen as 48" for convenience. Again, these parallelogram element dimensions remain constant as the skew angle of the deck is varied (Figure 3.4(a)). Note the reference position of the skew angle in Figure 3.4(a) as the complement is sometimes used in the literature.

3.2 Procedure

For the span chosen for the study, the maximum centerline moment in an orthogonal deck would occur under axle #3 (wheels #5 and #6 in Figure 3.2). Wheel #5 was therefore chosen as the reference from which the position of the truck will be measured. The truck will always be positioned as if it were moving parallel to the free edges of the deck. Since the program SKEW LOADER (see Appendix A) allows for input in terms of skewed coordinates, the position of wheel #5 will be given in such a coordinate system. The X input will be as measured from the left edge of the deck and the Y input will be the span (inclined) distance from the base support. For center loading, the position of wheel #5 will be input such that the center of axle #3 is over the transverse centerline of the deck (see Figure 3.4(b) for an example). The truck will be "moved" along the span direction while maintaining

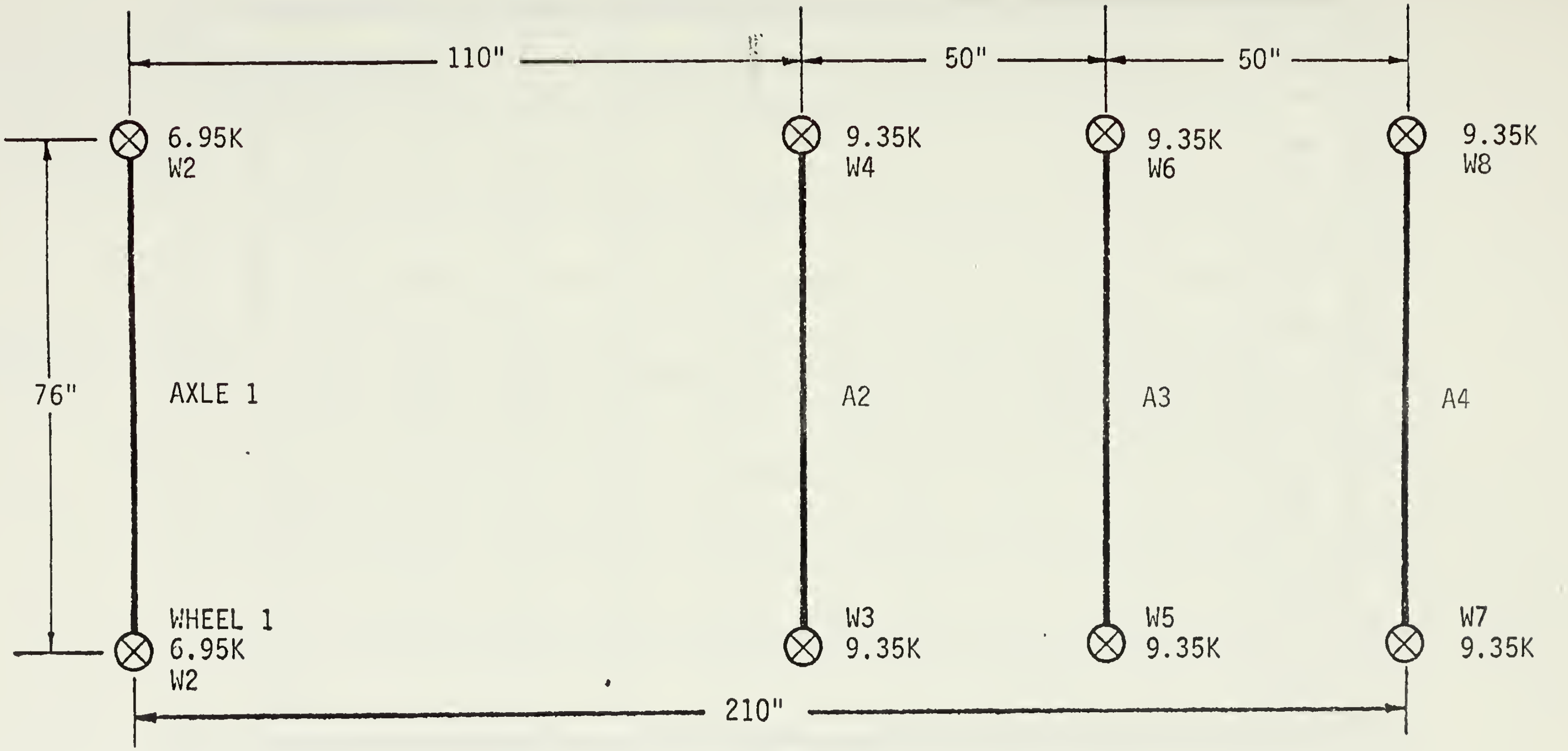


FIGURE 3.2 FDOT SU-4 TRUCK

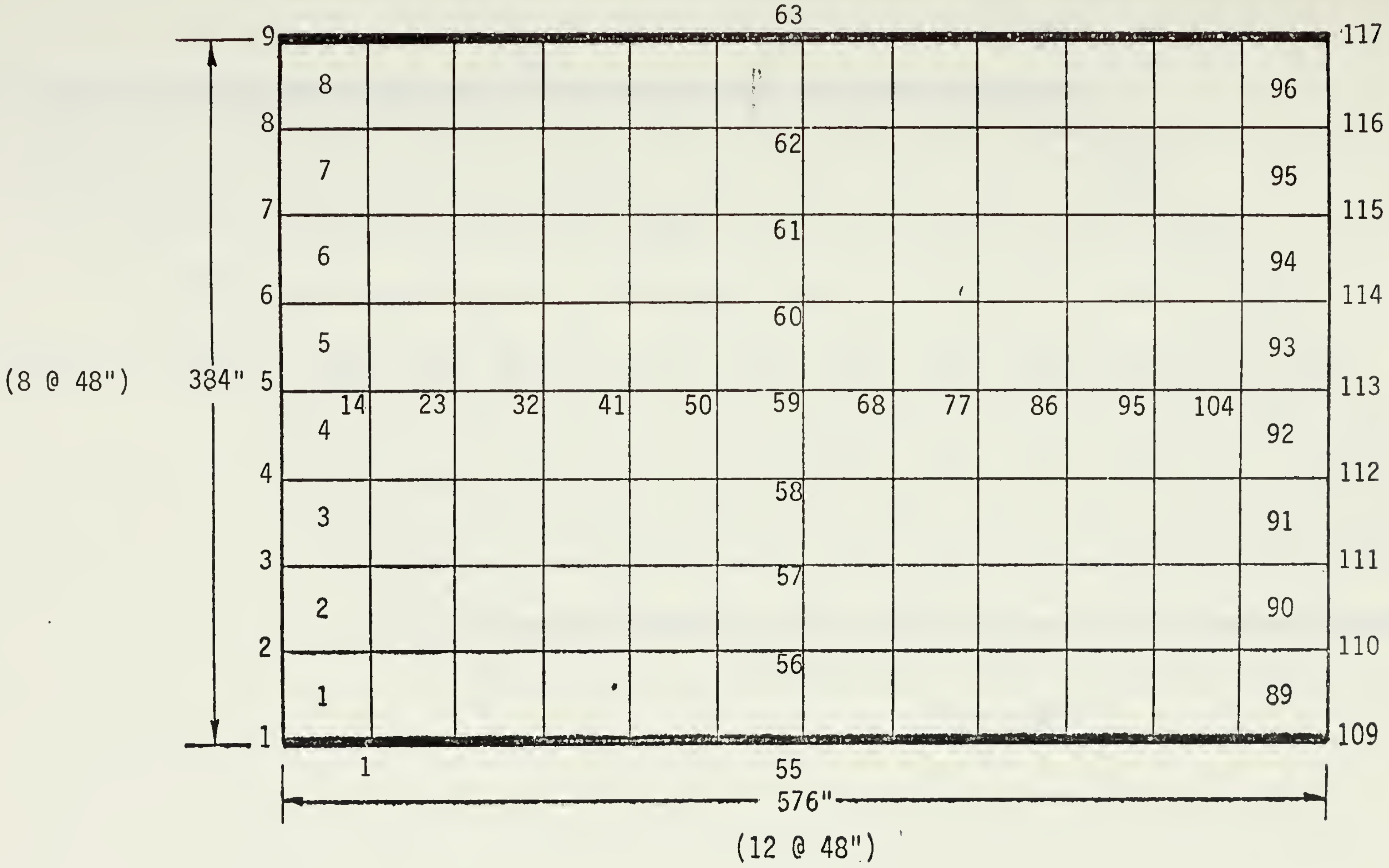


FIGURE 3.3 ORTHOGONAL DECK WSR = 1.50 USED IN PARAMETER STUDIES

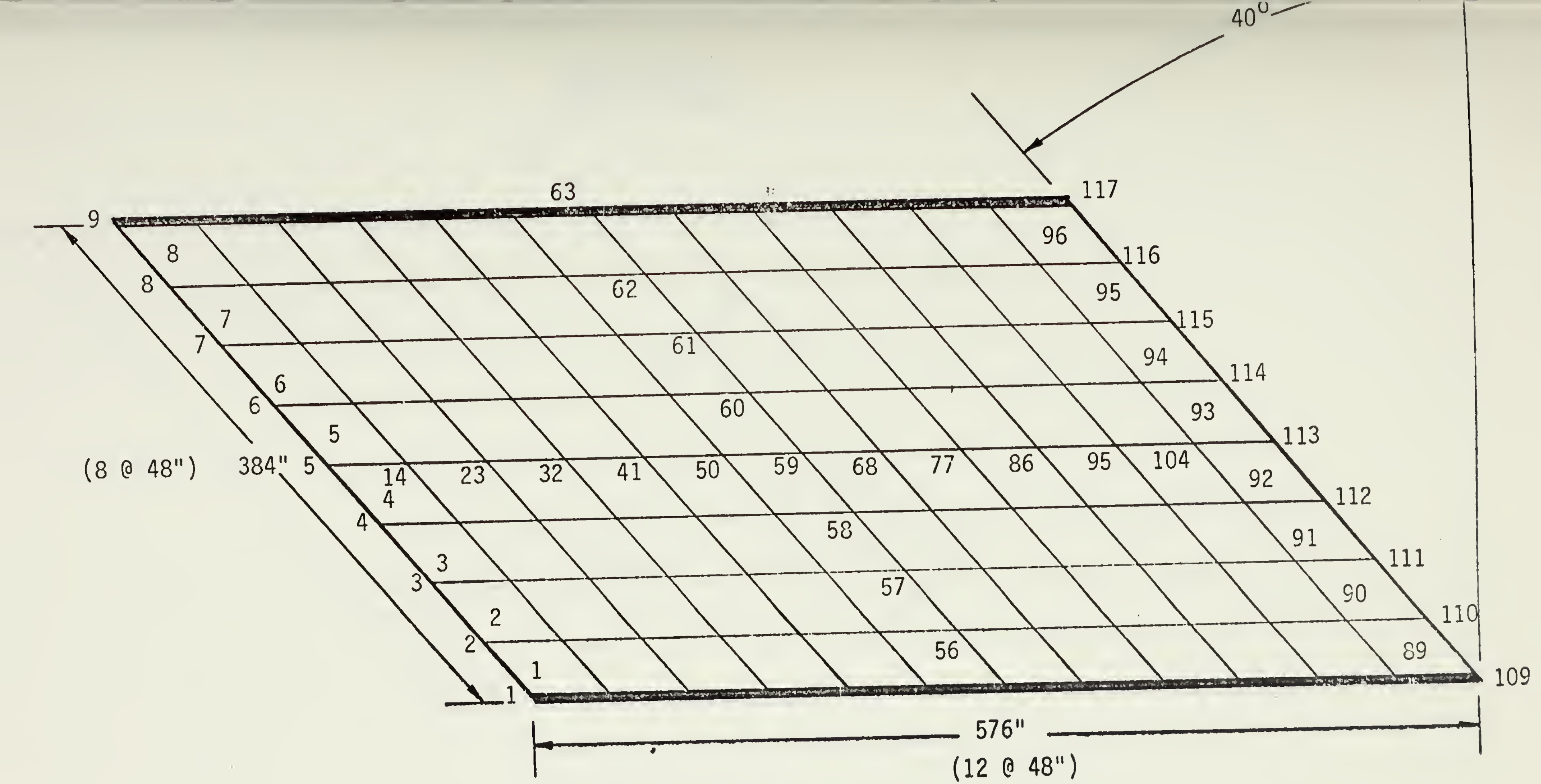


FIGURE 3.4 (a) 40° SKEW DECK WSR = 1.50 USED IN PARAMETER STUDY

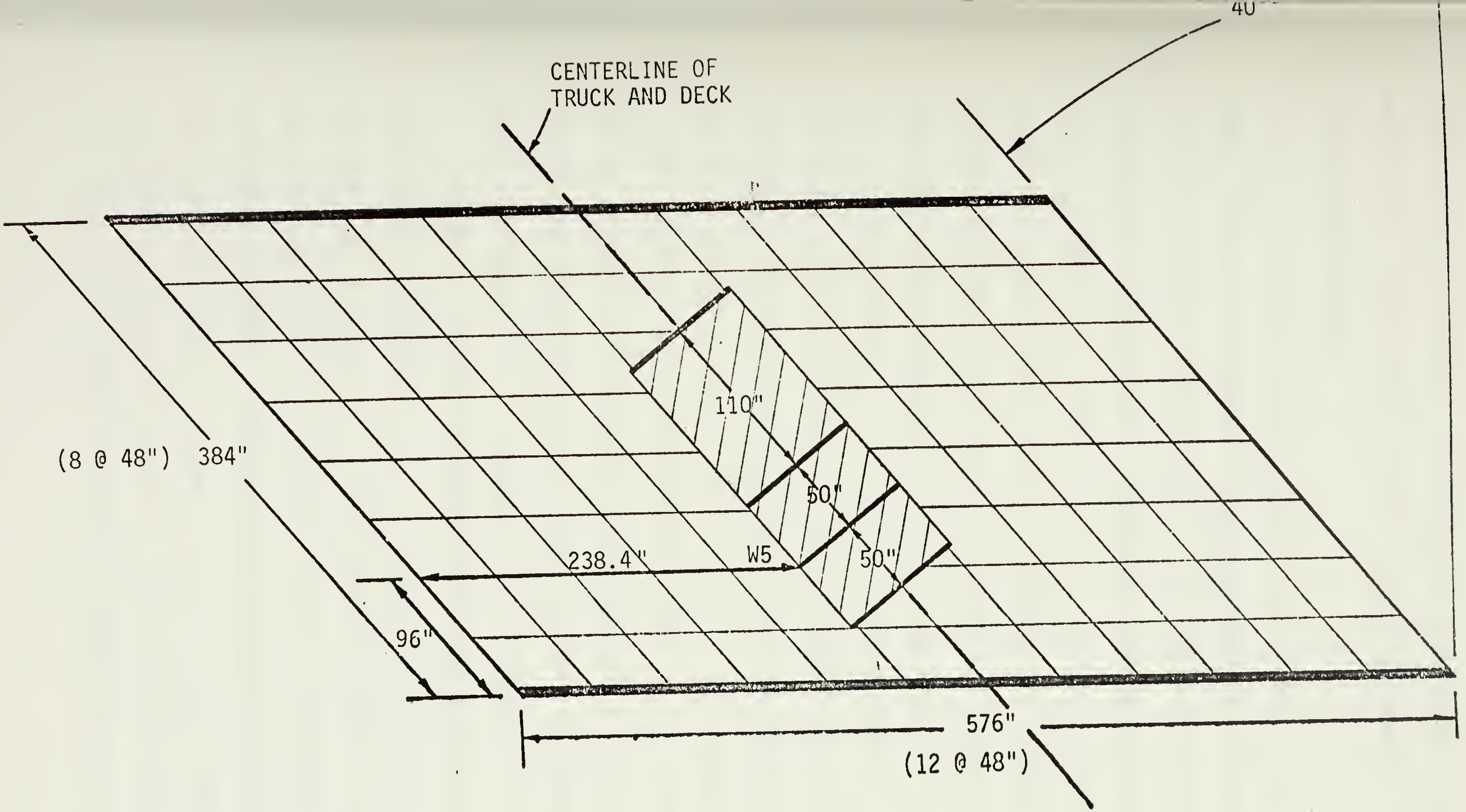


FIGURE 3.4 (b) EXAMPLE TRUCK POSITION FOR CENTER LOADING. NOTE CENTERLINE OF TRUCK COINCIDES WITH CENTERLINE OF DECK

this centered position. In this way the advantage of symmetry can be maintained on the right deck and axisymmetric loading can be maintained on the skewed decks.

The following discussion applies to the analysis procedure for load cases A and B (see Figure 3.1) where the WSR is 1.50 and the skew angle is 0 and 40 degrees, respectively. The remaining cases are handled in an analogous manner except for the edge loading cases which will be discussed separately. The first position of the truck is located at the transverse center and 96" (i.e., 2 elements) up from the base support. A finite element analysis is then run with the truck in this position and the principal moments at joint 59 (deck center) are obtained. The truck is then moved up 12" (i.e., one quarter element) in the span direction to a new position 108" from the base support, finite element analysis is again run with the truck in the new position and the principal moments at joint 59 again noted. This procedure is repeated at increments of 12" until the truck is 96" (i.e., 2 elements) away from the far support. The largest principal moment at joint 59 is plotted against the truck position in Figure 3.5 where the letter label of the graph corresponds to the respective case in Figure 3.1.

The above procedure is repeated for each of the remaining cases and the results are plotted for varied angles of skew at each WSR to obtain Figures 3.5, 3.7 and 3.9. In this way the effects of skew can be inspected separately for each WSR. Now for each of these graphs the transverse variation in moment must be studied on neighboring nodes in order to be sure that the moment at the transverse center is actually at or near the maximum in the deck. This is due to the fact that as deck skew angle is increased, the element edges are moved closer to the

wheels of the truck which may allow for greater localized moments at joints off-center. Thus each of the Figures 3.5, 3.7 and 3.9 showing moment variation with truck position is followed by a Figure 3.6, 3.8, and 3.10, respectively, showing the section moment variation across midspan in the vicinity of the peak moment. This section diagram examines the moment variation at midspan across two elements to the left and right of the peak and therefore plots for a total of 5 joints. For example, the joint 59 moment-position graph of case A (WSR = 1.50, skew = 0.0) peaks when wheel #5 is positioned 192" from the base support. Therefore to investigate the transverse variation in moment for this position of the truck, Figure 3.6 plots the moments at joints 41, 50, 59, 68 and 77. This graph is labeled "A-192-RT" giving the load case, truck position and deck skew angle, respectively.

For the case of edge loading a similar procedure is followed, though edge loading is considered only for the cases with a WSR of 1.00. The truck is again placed 96" from the base support but now 48" (i.e., one element) in from the left free edge. A finite element analysis is run with the truck in this position and the moment at joint 5 is noted. The truck is then moved across the span in increments of 12" with a finite element analysis run for each successive position. In each case the moment at joint 5 is noted, and as before the truck is stopped at 96" from the far support. The moment at joint 5 (the edge node at midspan) is plotted against each position of the truck and is shown in Figure 3.11 for skew angles of 0, 20 and 40 degrees. In a similar procedure as for the center loading cases, the transverse moment variation is plotted in Figure 3.12 which examines the moments across 4 elements starting from the left edge. For this parameter study,

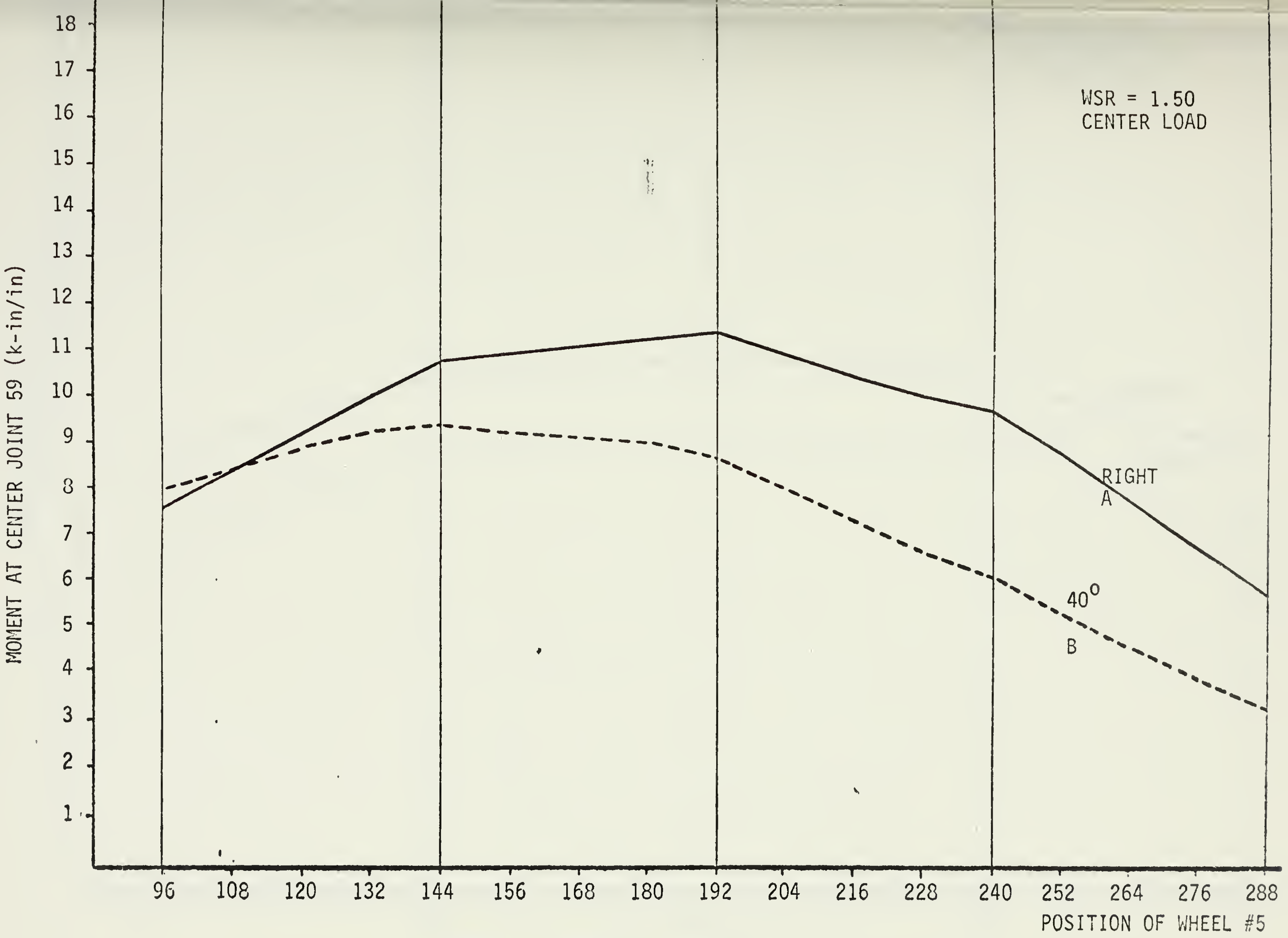


FIGURE 3.5 MOMENT VARIATION WITH TRUCK POSITION

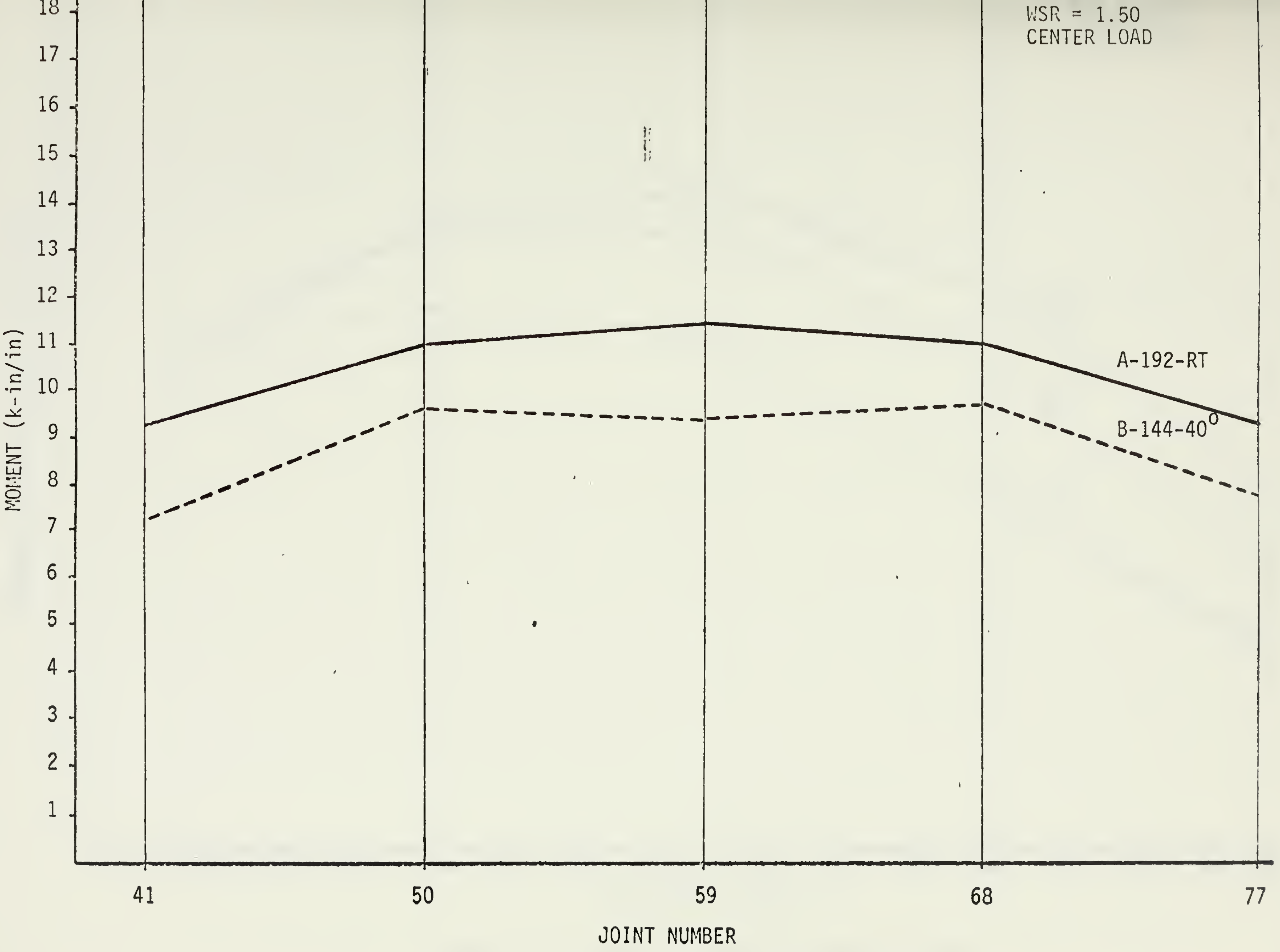


FIGURE 3.6 MOMENT VARIATION ACROSS MIDSPAN

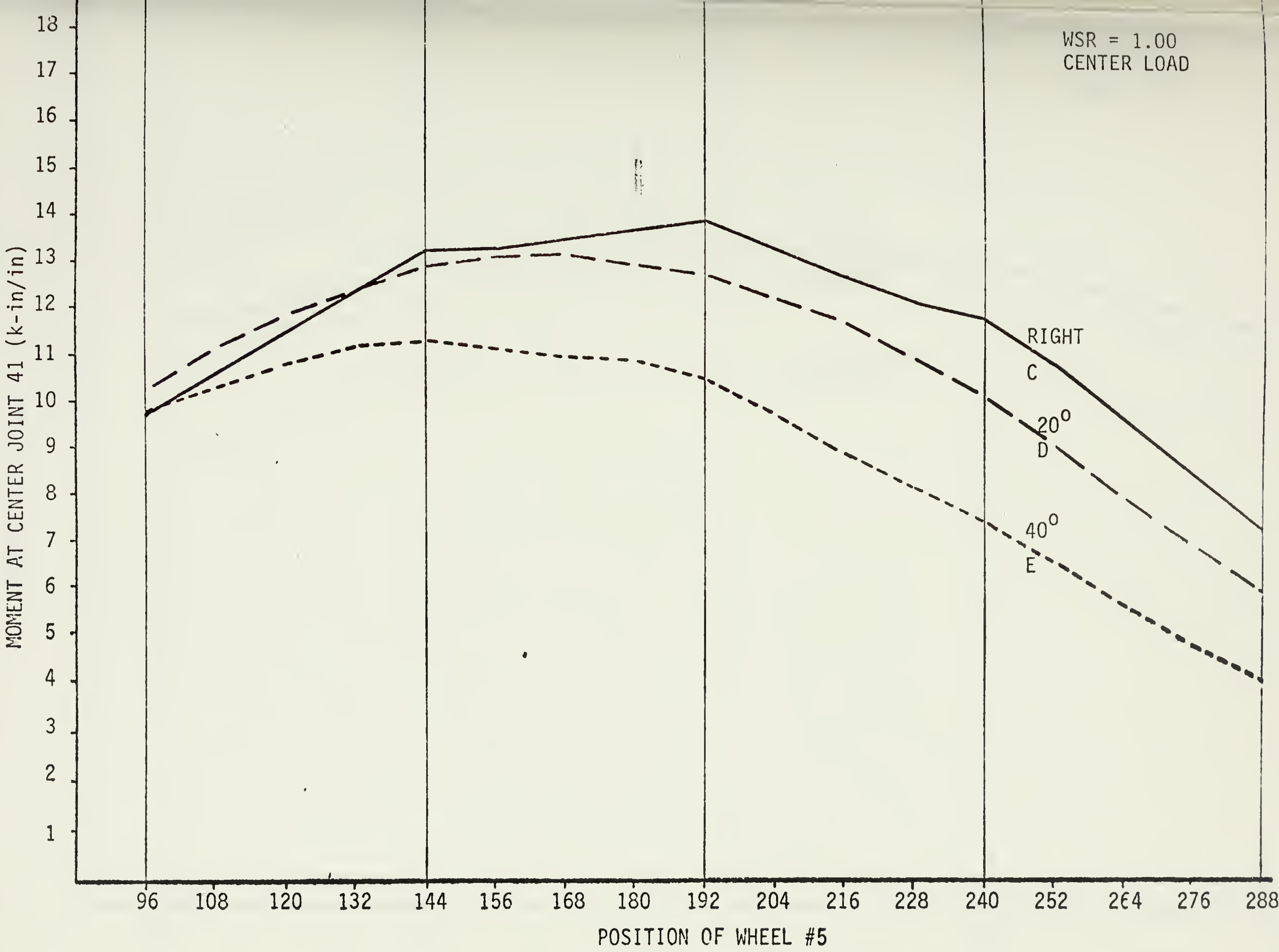


FIGURE 3.7 MOMENT VARIATION WITH TRUCK POSITION

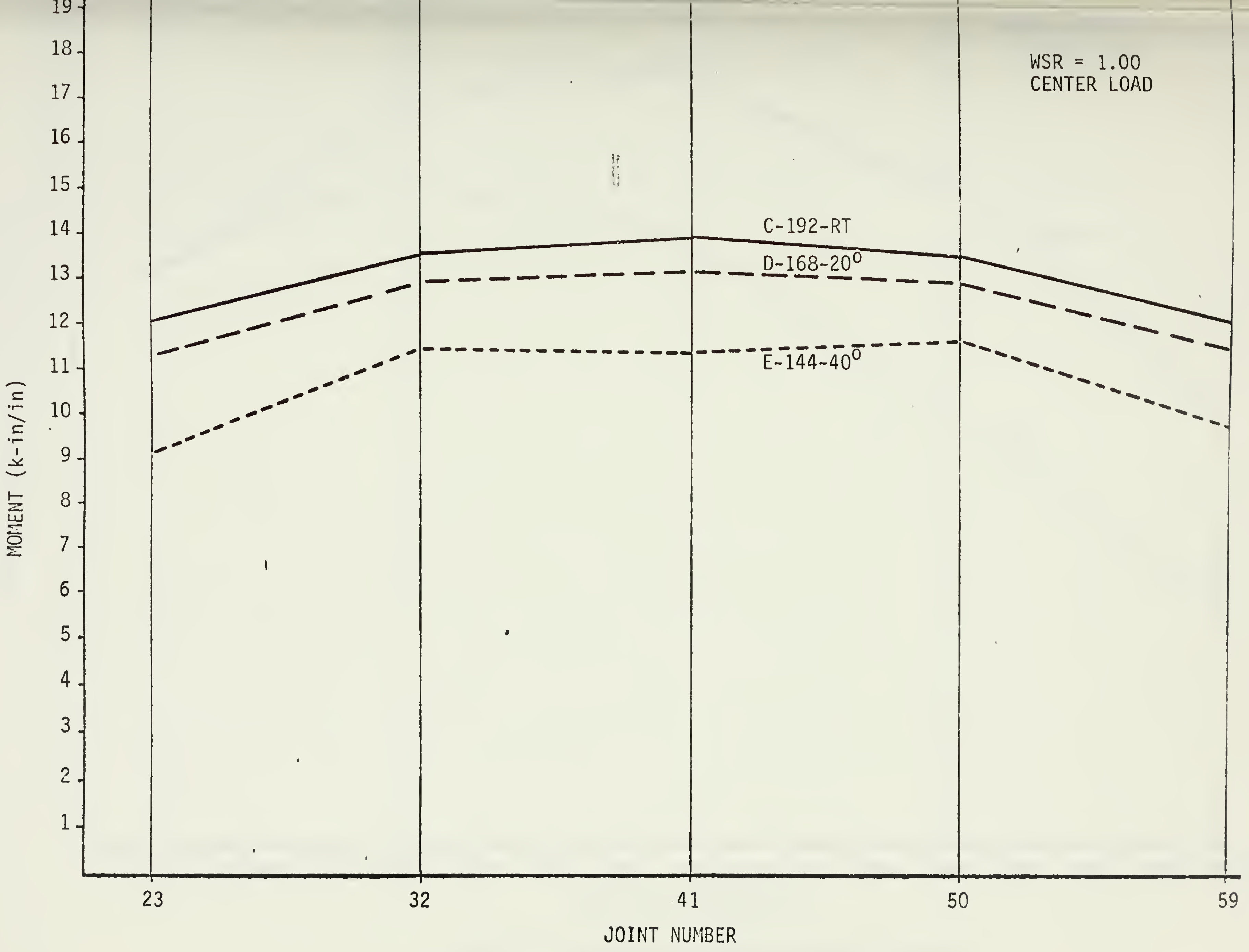


FIGURE 3.8 MOMENT VARIATION ACROSS MIDSPAN

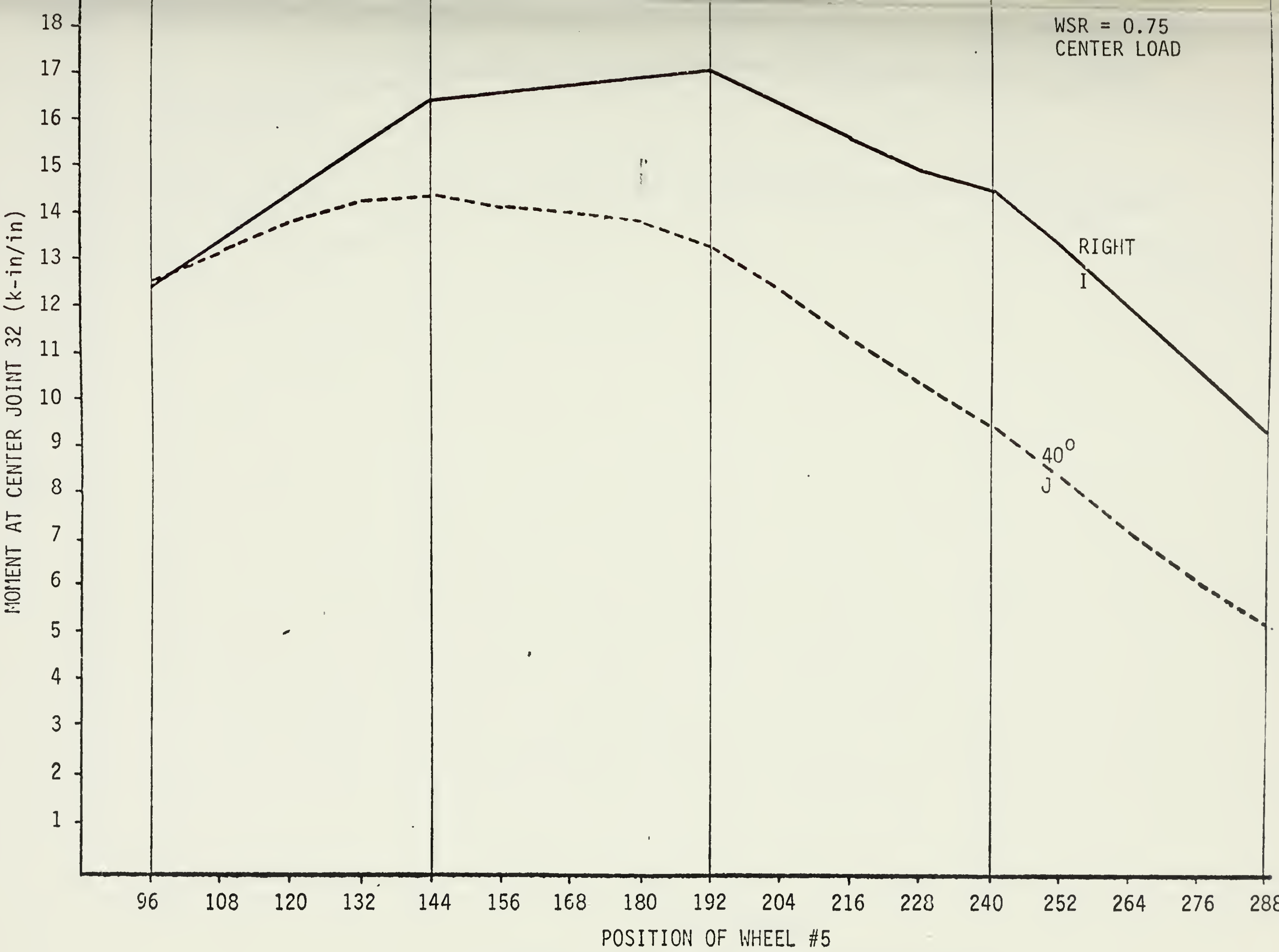


FIGURE 3.9 MOMENT VARIATION WITH TRUCK POSITION

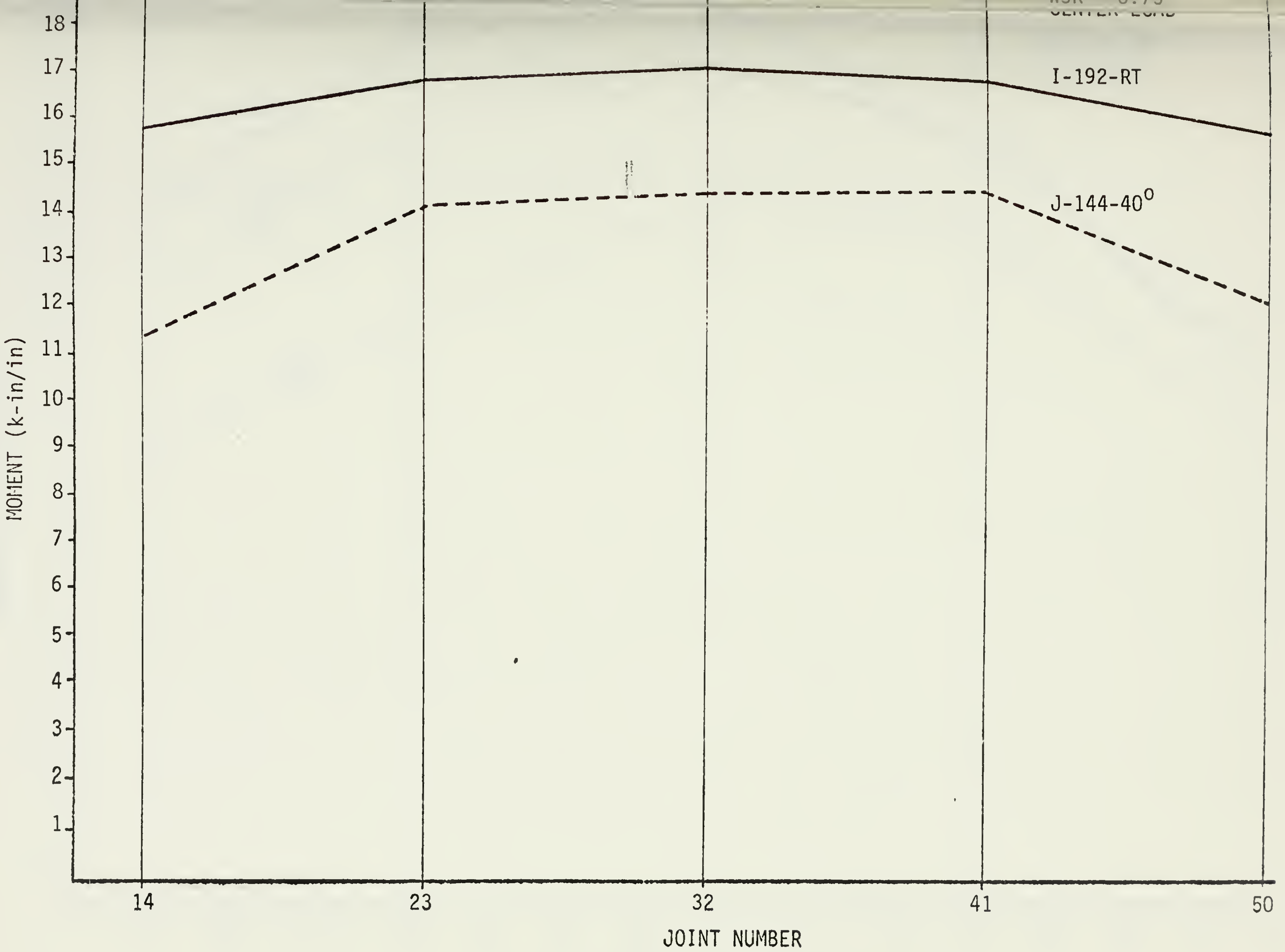


FIGURE 3.10 MOMENT VARIATION ACROSS MIDSPAN

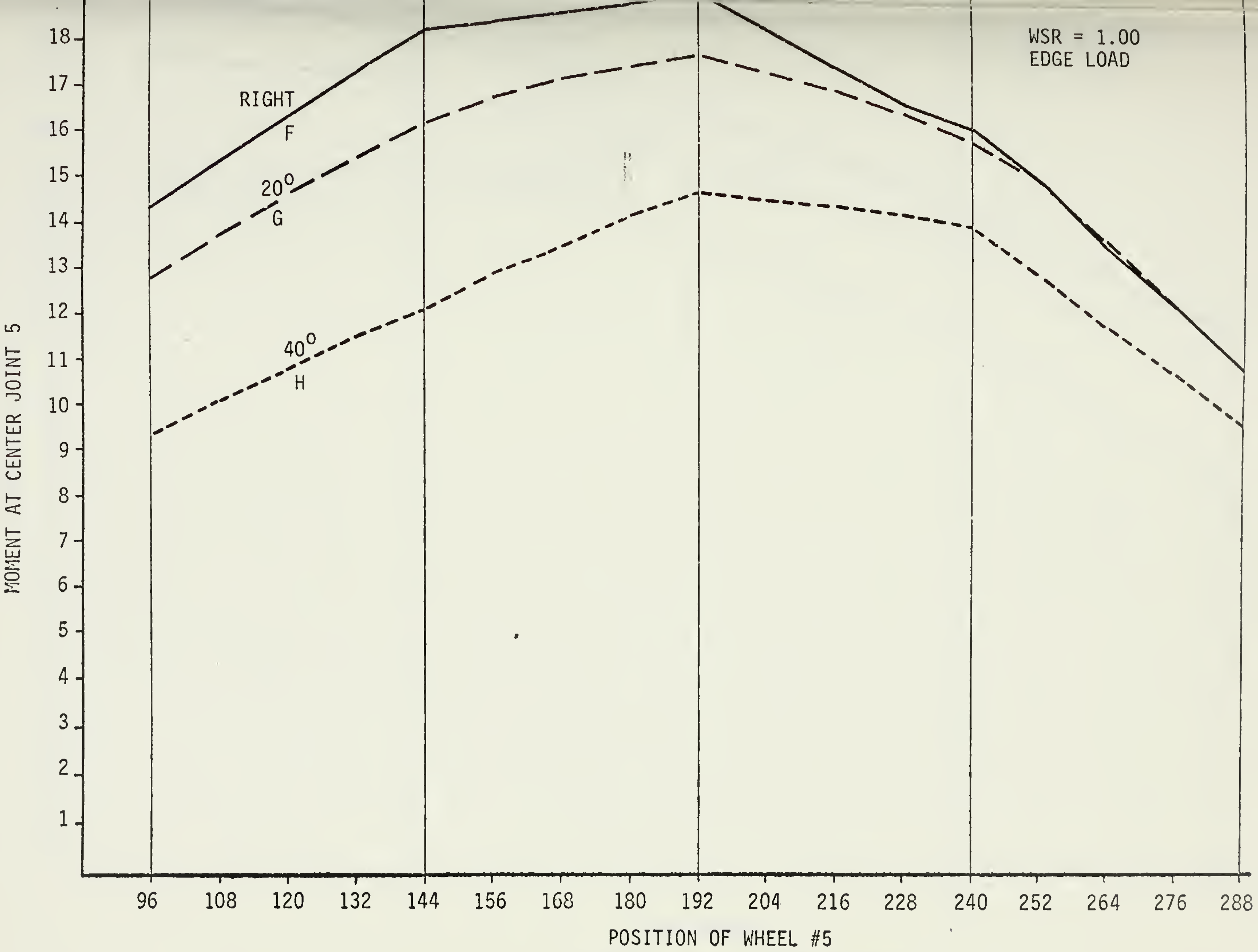


FIGURE 3.11 MOMENT VARIATION WITH TRUCK POSITION

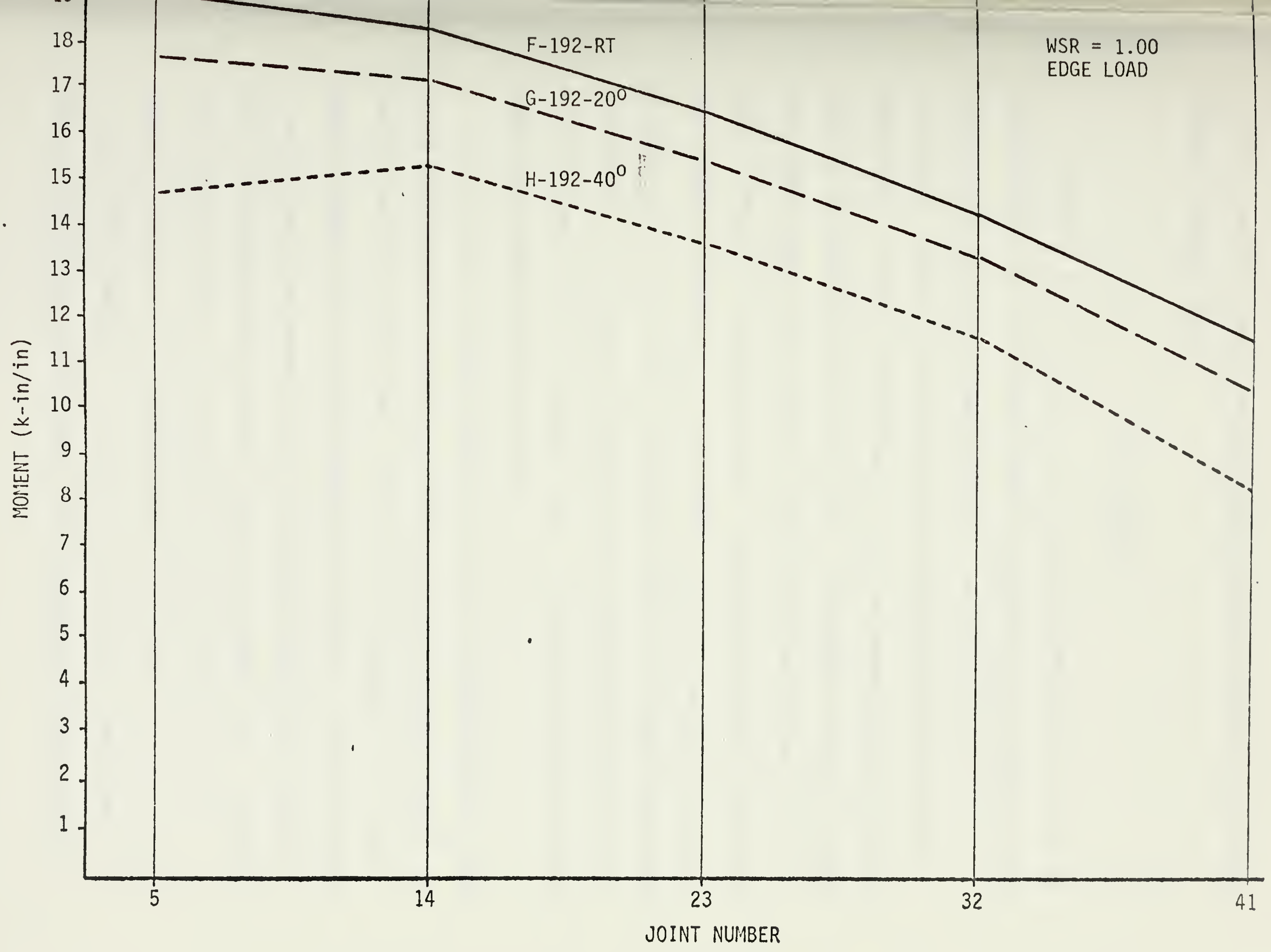


FIGURE 3.12 MOMENT VARIATION ACROSS MIDSPAN

including both the center and edge loading cases, a total of 170 finite element runs were made.

3.3 Results

In many of the skewed decks, the maximum moment does not occur at the same joint as in the corresponding orthogonal deck. However, it is seen that the increase in moment from the corresponding joint never exceeds 3%. Therefore the moment at the same joint will be used for comparison. It must be noted however, that the moments generally do not peak for the same position of the truck. For example, Figure 3.9 (WSR = 0.75, center load) shows that the right deck attains maximum moment at joint 32 when the truck position (i.e., wheel #5) is at 192" from the base support. The 40 degree deck however peaks earlier when the truck position is at 144". This is the general trend in all center load cases studied here. The right deck always peaks at 192" while the 40 degree deck peaks about 48" (one element) sooner. As might be expected, the 20 degree deck peaks about 24" earlier.

The fact that the moments peak earlier for increased angles of skew can be attributed to the effect of wheel #6 (also a critical wheel) reaching the deck center sooner. This allows the moment at the deck center to peak earlier and also accounts for a portion of the reduction in maximum principal moment from the right deck because both wheels 5 and 6 are not lying along the span center at the same time. The right deck peaking at 192" is to be expected as this corresponds to the position where the critical wheels are at span center. For the case of the edge loading however, it is noted that the joint 5 moment peaks occur when the truck is positioned at 192" regardless of the angle of

skew. Figure 3.12 shows that the principal span moment decreases from the left edge of the deck at low angles of skew, though it increases slightly at joint 14 at 40 degrees. This would seem to indicate that the localized effects of the free edge are less pronounced at greater angles of skew.

Table 3.1 summarizes the key data for the parameter study. It is interesting to note that the greater WSR's allow for the greater percentage in principal moment reduction for increased angles of skew. For example, it is seen that the WSR of 1.50 has a moment reduction of 24.3% in moving from the right deck to 40 degree skew deck. This can be compared to only a 15.6% reduction for the WSR of 0.75. The rate of moment reduction is also non-linear as evidenced by the table entries of WSR = 1.00 (center loading). Here the moment reduction for the first 20 degrees (i.e., 0 to 20) is only 5.4% while for the second 20 degrees (i.e., 20 to 40) is 13.5%. Therefore the rate of moment reduction is increased with an increase in skew angle. In the case of edge loading, the behavior is similar except that the percentages are somewhat increased. It is important to note that these decreases in maximum principal moment do not necessarily allow for commensurate reduction in reinforcing steel. The angle at which the reinforcement is laid and the direction of these principal moments play an important role in the amount of steel required. These effects will be discussed in greater detail in Chapter 4.

3.4 Contour Plot Description

Appendix C shows the contours of major principal moment and Z (transverse) displacement for skew angles of 0 and 40 degrees. These

TABLE 3.1 PARAMETER STUDIES SUMMARY

	WSR	MAXIMUM PRINCIPAL MOMENT (k-in/in) / % REDUCTION FROM RIGHT		
		RIGHT	20^0	40^0
CENTER LOADING	1.50	A 11.49 --	NOT STUDIED	B 8.70 24.3%
	1.00	C 13.90 --	D 13.15 5.4%	E 11.37 18.2%
	0.75	I 17.07 --	NOT STUDIED	J 14.41 15.6%
EDGE	1.00	F 19.11 --	G 17.68 7.5%	H 14.72 23.0%

A INDICATES CASE "A" FROM FIGURE 3.1

plots were obtained from GTSTRUDL graphics and plotted on a Tektronix print device from the scope environment.[1] The loading conditions selected for comparison were a central 10 kip load and the peak SU-4 central load. The WSR is 1.50 throughout.

Figures C.1 and C.2 show the effect of skew angle on the major principal moments under a central 10 kip load. Note that the contour gradient remains essentially perpendicular to the supports. This same effect can be seen on Figures C.3 and C.4 (SU-4 peak loading case) where the path of "steepest descent" is nearly along the shortest line to the supports. The concentration of contours near the obtuse corner show that the major principal moment increases more quickly (along a line towards the center) than at the acute corner. Figures C.3 and C.4 can be compared to the transverse moment variation graphs for load cases A and B as shown in Figure 3.6.

Figures C.5 through C.8 illustrate the variation in deflected shape between skew angles of 0 and 40 degrees. Figures C.4 and C.5 refer to the central 10 kip load while C.7 and C.8 refer to the SU-4 peak load. It is seen that the behavior is similar for both loading cases. As would be expected physically, the displacement gradient is perpendicular to the supports and the direction of "minimum descent" is along the span centerline.

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[1] The scope environment is a characteristic operating domain in GTSTRUDL which allows for interactive graphics at the terminal CRT.

CHAPTER 4

REINFORCEMENT

4.1 Introduction

The safe and economic proportioning of reinforcement is critical in bridge deck design. Ideally, the re-bars should be laid orthogonal to the principal design moments. However since the principal angles vary from point to point throughout the deck for even a single loading case, the reinforcement cannot be placed ideally in a practical sense. Furthermore since design is often based on a series of different loading cases, the principal angle will often vary at the point as well. Therefore the concept of ideal reinforcement for a bridge deck is a trivial one.

Certain general directions for the reinforcement are a good deal more economical (in terms of required steel quantity only) than others. Cope [2] has studied orthogonal reinforcement for skewed decks and compared the experimental results of placement parallel to the supports versus parallel to the skewed edge. The results of this study will be discussed in more detail in section 4.3. Orthogonal reinforcement in skewed decks however, has severe limitations in practice. Since a large number of re-bars of different lengths are required for this design, a great deal of extra labor is required for cutting and placing the reinforcement. Therefore, though it is generally desireable to have reinforcing steel running perpendicular to the supports (to resist the span moment), such an arrangement is usually not practical.

Discussions with FDOT engineers indicate that most reinforcement in skewed decks today is not orthogonal. The primary reinforcement is generally laid parallel to the deck edges and the transverse reinforcement is laid parallel to the supports. This is certainly the easiest from a construction point of view, but for largely skewed bridges it may require a considerable amount of extra reinforcement. Morely [16] has developed a design process for non-orthogonal reinforcement in skewed decks. Though the method may be tedious for practical design problems witout the aid of computer, it serves well to illustrate the effects of skewed reinforcement. This design will be discussed in section 4.4 and some examples worked which are relevant to the parameter study of Chapter 3.

Even though the STRUDL analyses are purely elastic, it is relevant to first examine the failure mechanisms of skewed decks by the theory of yield lines before discussing reinforcement in detail. For a more complete discussion on yield line theory and applications, several texts are available such as [7], [19].

4.2 Failure Analysis by Yield Lines

Analysis of plate capacity can be determined theoretically by the principle of virtual work and an assumption of a yield line pattern. The work done externally by the applied forces acting through the plate deflection is equated to the internal work done by the rotation of the moments acting on the yield lines. The collapse load can then be solved for in terms of the ultimate unit moment capacity of the plate. Often the main problem in the yield line approach is determining the correct (or critical) failure mechanism to be analyzed. Yield line patterns can

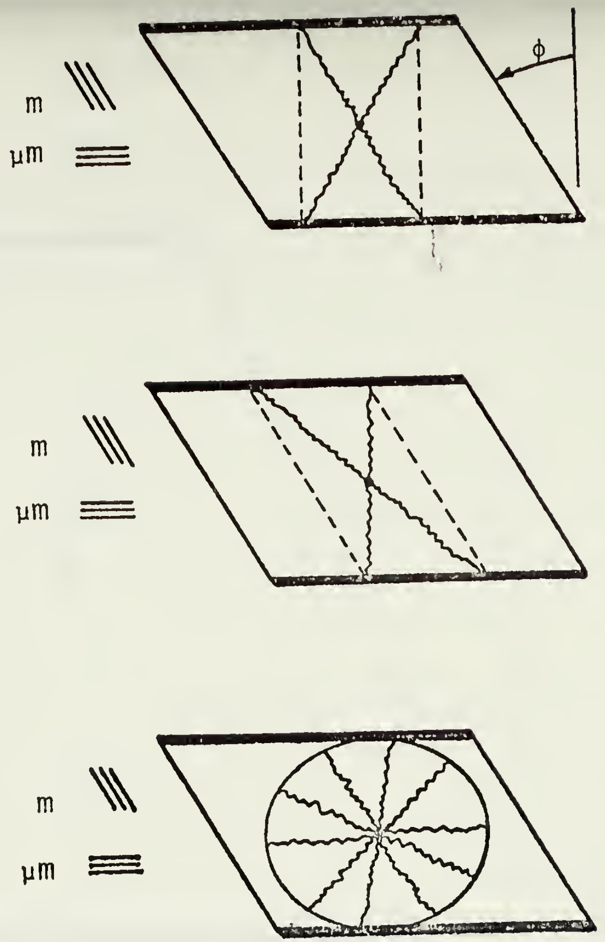
be assumed from some experience or from some generally established guidelines. Hughes [7] gives some such guidelines, although generally the critical pattern is not easily found even for some rather simple geometries.

For example, Hughes [7] shows three possible failure mechanisms for a simply supported skewed span as shown in Figure 4.1. The deck is given a central point load W and the orthotropic reinforcement is oriented parallel to the deck edges as is generally used in practice (see Figure 4.1). The figure and equations have been modified to agree with the conventions used in this report thusfar. It is seen that the elliptical fan pattern represents the least allowable failure load. Since bridge decks are generally not subjected to a single central concentrated load, this case may be of purely academic interest. However, in deriving the critical load for the elliptical failure mechanism, Hughes outlines (and proves) a very useful principle for obtaining an affine isotropic right slab from an orthotropic skewed one. This procedure is discussed below.

A skewed deck such as that shown in Figure 4.2(a) can be transformed into an equivalent orthogonal deck for the purposes of analysis. The equivalent right deck (or so called "affine deck") shown in Figure 4.2(b) is of course much easier to analyze and can be obtained by the following rules:

(a) Deflections are identical at corresponding locations in both decks.

(b) Given that m and μm are the ultimate resisting moments in the reinforcing direction of the actual deck, then the affine deck has ultimate resisting isotropic moment m.



MECHANISM 1 (RECTANGULAR)

$$W = 8\sqrt{\mu + \sin^2\phi}\ (m \cos\phi)$$

(LARGEST LOAD)

MECHANISM 2 (PARALLALOGRAM)

$$W = 8\sqrt{\mu}\,(m \cos\phi)$$

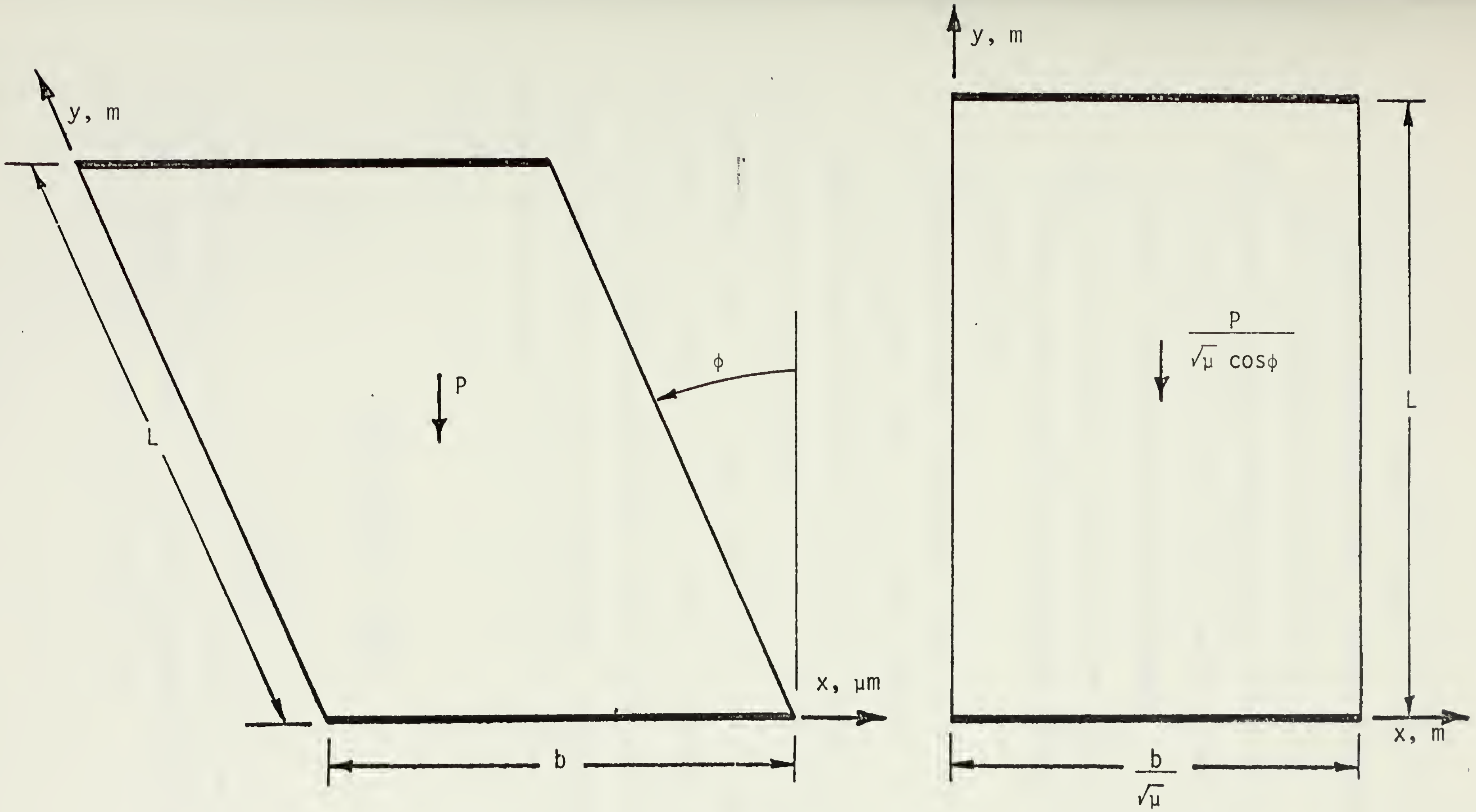
(IN BETWEEN)

MECHANISM 3 (ELLIPTICAL FAN)

$$W = 2\pi\sqrt{\mu}\quad (m \cos\phi)$$

(CRITICAL LOAD)

FIGURE 4.1 THREE FAILURE MECHANISMS FOR CENTRALLY LOADED SKEWED SPANS (FROM HUGHES [7])



(a) ACTUAL DECK

(b) AFFINE DECK

FIGURE 4.2 AFFINE DECK TRANSFORMATION

(c) Given that the Y coordinate axis is along the m reinforcement direction in the actual deck, then all distances measured in the Y direction are the same for both decks.

(d) Given that the X coordinate axis is along the μm reinforcement direction in the actual deck, then it is taken at a right angle to the Y axis for the affine deck.

(e) In order to obtain a dimension in the X direction of the affine deck, divide the corresponding length on the actual deck by $\sqrt{\mu}$.

(f) Divide the loads on the actual deck by $\sqrt{\mu}\cos\phi$ to obtain the corresponding loads on the affine deck.

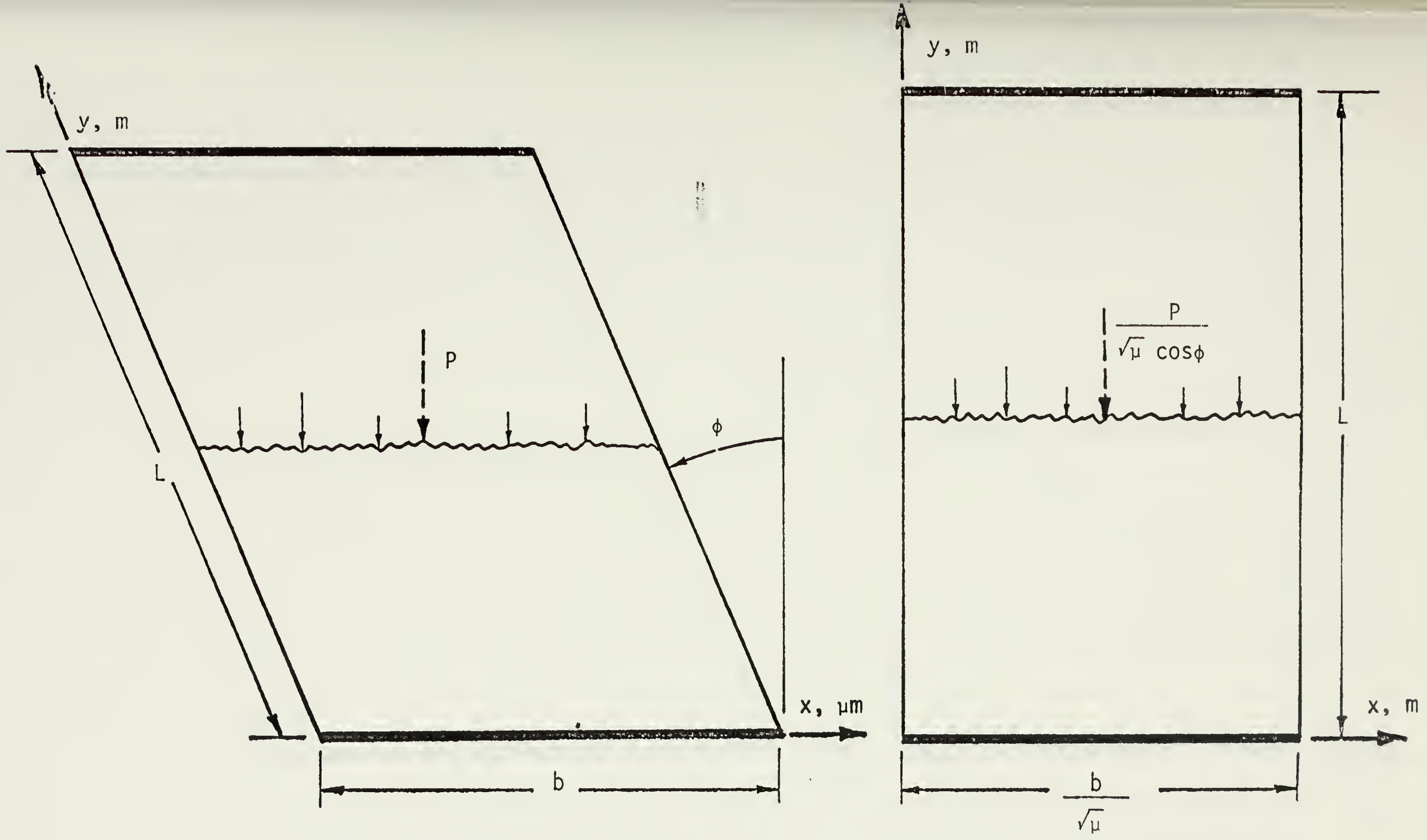
Using the above procedure, an interesting result is obtained if the deck in Figure 4.2(a) is analyzed assuming a yield line occurs across midspan (see Figure 4.3). This assumption for the failure mechanism may be valid for the multiple load cases arising on bridge spans. The load P is a sum of the concentrated wheel loads acting across midspan and should cause failure to occur in beam action. If m represents the unit moment resisting capacity of the affine deck in Figure 4.3(b), then by statics

$$\left(\frac{L}{4}\right)\left(\frac{P}{\sqrt{\mu}\cos\phi}\right) = m\left(\frac{b}{\sqrt{\mu}}\right)$$

or

$$m = \frac{PL}{4b\cos\phi}$$

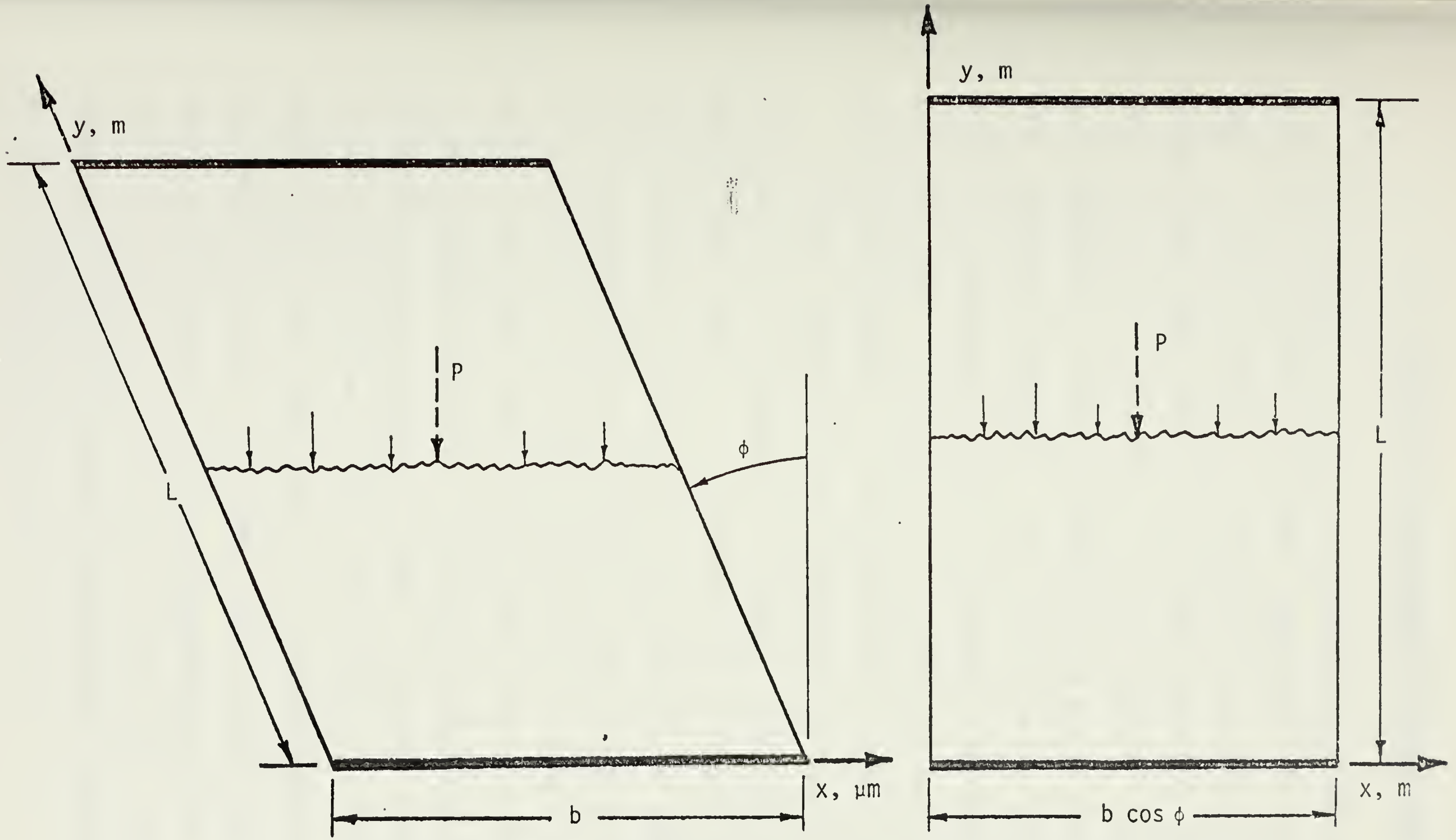
Therefore the deck of Figure 4.3(a) is equivalent to an orthogonal deck of span length L and base of a length diminished by the cosine of the angle of skew. This illustrated in Figure 4.4.



(a) ACTUAL DECK

(b) AFFINE DECK

FIGURE 4.3 BEAM ACTION FAILURE



(a) REQUIRED $m = \frac{PL}{4b \cos \phi}$

(FROM AFFINE DECK)

(b) REQUIRED $m = \frac{PL}{4b \cos \phi}$

(FROM STATICS)

FIGURE 4.4 EQUIVALENT DECKS IN BEAM ACTION FAILURE

4.3 Orthogonal Reinforcement in Skewed Decks

An experimental investigation was conducted by Cope [2] on the effects of orientation of orthogonal reinforcement in 45 degree skewed decks. Although orthogonal reinforcement is generally not used in skewed bridge design, the study finds some interesting results which may lead to a better understanding of flexural behavior. The test procedure was fundamentally a comparison between two 45 degree skew slabs, each with orthogonal reinforcement. Slab A had secondary reinforcement parallel to the supports. Slab B had primary reinforcement parallel to the skewed edges. The propagation of cracking and deflections in the two slabs were examined for increasing loads in various locations.

The tests showed considerable behavioral differences in the two slabs in the areas of deflections, cracking and failure mechanisms. Sagging cracks were first initialized on slab A running towards the free edges and parallel to the supports, and under heavier load hogging cracks appeared at the obtuse corners. Initial sagging cracks in slab B occured earlier (at about 80% of the load for A) as did the hogging cracks at the obtuse corners (at about 67% of the load for A). The cracking patterns were similar in direction and spacing, though somewhat straighter and more continuous in slab B. The modes fo failure of the two decks were different as well. Slab A initially failed in shear on the free edge at the obtuse corner. At about 40% higher load, slab B developed a top surface crack between the two obtuse corner supports which was wide enough to produce a discontinuity in slope. Both slabs were able to carry considerably more load after their initial failures. Ultimate failures were punching shear at the obtuse corner for slab A and excessive deflections for slab B.

The report concluded that the behavior of skewed decks is strongly influenced by the direction of the reinforcement. When the reinforcing is placed orthogonally and parallel to the supports, the slab is stiff and behaves well under service loads. However, heavy concentrated loads are not distributed well across the slab and a large reactive force develops at the obtuse corner. This led to local failure in the test. For slabs with orthogonal reinforcement parallel to the free edges, a more flexible slab results which better distributes moments due to concentrated loads. Greater deflections can occur and ultimate failure load is increased, though again hogging cracks at the obtuse corner may limit servicibility.

The results of this study are consistent with a finding by Kennedy [11] which experimentally investigated the stress near corners of simply spanned skewed plates. Here too it was found that stresses near the obtuse corners are significant and increase with increasing angles of skew. Furthermore, the stress at the obtuse corners may exceed the maximum stress at center span. Kennedy then recommends that the obtuse corners of concrete skewed decks be heavily reinforced top and bottom in directions parallel and perpendicular to the supports as well as parallel to the free edge. The accute corners should be heavily reinforced at the bottom and nominally reinforced at the top. The direction of reinforcement near the acute corners should be perpendicular to a line between them and parallel to the free edge.

4.4 Design for Skewed Steel

A design procedure was worked out by Morely [16] on proportioning skewed reinforcement which is laid parallel to the edges of the deck.

Since this is generally the orientation used in construction, this method could prove useful in design practice. Equations are developed based on the optimum proportionment of steel to resist a moment triad at a point in the deck. Therefore the method begins with the assumption that elastic analysis has been performed for a load case on the deck and that a set of three moments (two bending and one torsional) are known at the point considered. The design procedure is then carried out using a series of charts, tables and equations given in the reference.

Morley's design for skew reinforcement to resist a single moment triad consists of the following steps:

(a) Orient the sign convention of the known moment triad in accordance with Figure 4.5

(b) Compute $\frac{M_x}{|M_{xy}|}$, $\frac{M_y}{|M_{xy}|}$ and $k = (\sigma_y l_a/|M_{xy}|)$ using a rough approximation for l_a. ($k=0$ if no minimum steel is specified)

(c) Enter the charts with the nearest values of ϕ and k and locate the appropriate region

(d) Evaluate a_{1x}, $a_{1\phi}$, a_{2x}, $a_{2\phi}$, θ_s and θ_h from the appropriate equations in the tables

(e) Compute l_a by an iteration equation of section equilibrium

(f) Compute A_{1x}, $A_{1\phi}$, A_{2x}, $A_{2\phi}$, from $a_{1x} = \sigma_y l_a A_{1x}$ $(x \leftrightarrow \phi)$

where these variables and others used in the design examples are defined as follows:

A_{min}	specified minimum steel are per unit slab width
a_{1x}, $a_{1\phi}$	'area functions' with dimensions of moment
d_e, d_o	depths for bottom and top steel, respectively
k	failure factor connecting A_{min} and applied twising moment M_{xy}

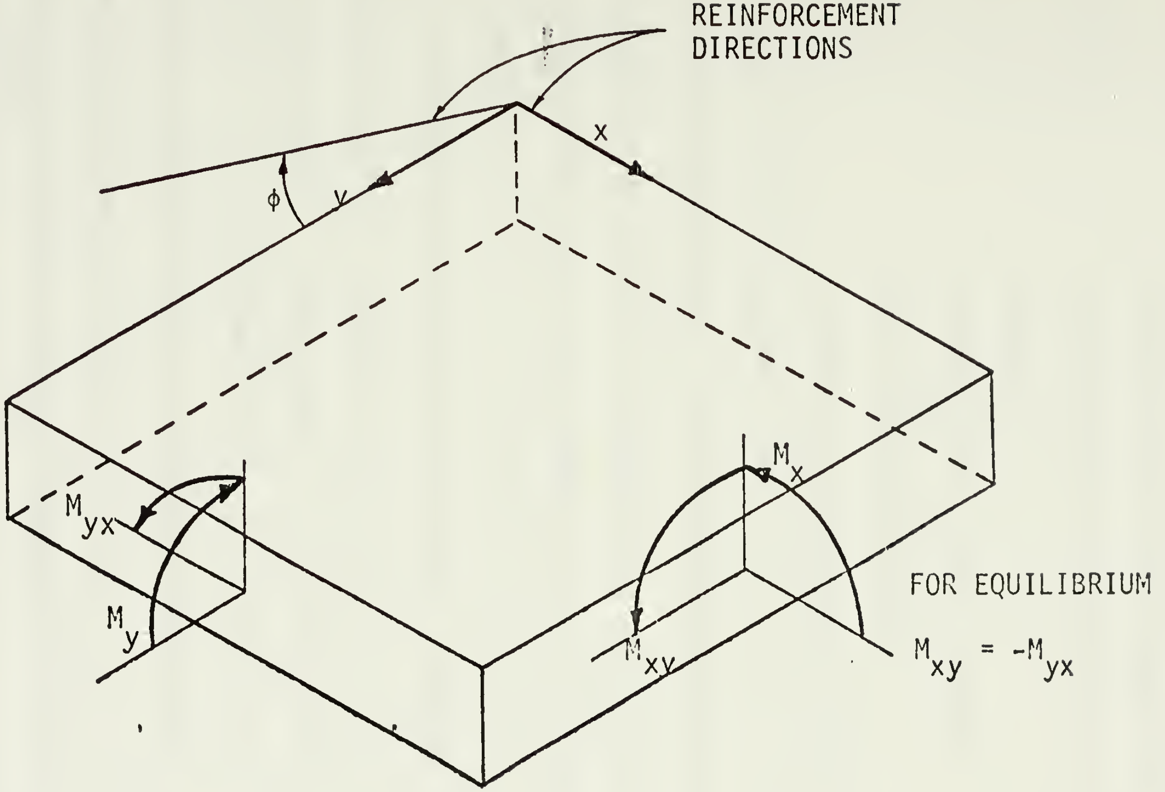


FIGURE 4.5 MORLEY'S [16] SIGN CONVENTION FOR NON ORTHOGONAL REINFORCEMENT DESIGN EXAMPLES

l_a	lever arm of tensile steel in failure direction
M_x, M_y, M_{xy}	bending and twisting moments per unit slab width
M_1, M_2	principal moments
T_1, T_2	total resolved steel forces in failure direction at bottom and top, respectively
θ_s, θ_h	optimum failure directions for sagging and hogging
ϕ	skew angle of reinforcement
σ_y	yield stress of steel
σ_c	value of concrete stress block at failure

A total of five examples will be worked here to examine the effects of skewed reinforcing steel. The first three examples show the extra reinforcement required for a 20 degree skew deck over a right deck when designing for the central span moment for a 100 kip load. Examples 4 and 5 similarly illustrate for the peak moments produced by SU-4 truck. It should be noted that this design procedure could prove very tedious for practical problems without the aid of a computer. This is because the moments at many points in the slab would have to be considered for various combinations and positions of vehicle loads. The results for each trial run are very sensitive to the sign and magnitude of the torsional moment at the point considered. These multiple moment triads must be considered and the minuimum steel retained at each successive iteration. Morley makes allowances for this in an extension of the procedure for multiple moment triads along with some guidelines for a rational approach to design.

It should be understood that in the examples which follow, the steel in the slab is not completely designed for the given loading

condition, since only the moment at the geometric center is considered in each case. The examples are intended only to illustrate the effects of non-orthogonal reinforcement at a point for a few different load conditions. Morely emphasizes the effects of the sign of the torsional moment by working two similar examples of a 20 degree skew deck. The first has a point subjected to M_y = +50 k-in/in, M_x = +35 k-in/in and M_{xy} = +20 k-in/in and the total required steel is found to be 3.96 in^2/ft. In the second example the sign of M_{xy} is changed to -20 k-in/in and the total amount of steel becomes 8.20 in^2/ft, or roughly twice the amount. This increase occurs because the direction of the major principal moment is shifted, due to the sign change of M_{xy}, from within the acute angle between the reinforcement to the obtuse angle. This reduces the unit effective reistance of the steel, and hence a greater amount is required.

For the examples discussed below, reference is made to Figure 4.6 and the following data is applicable to each:

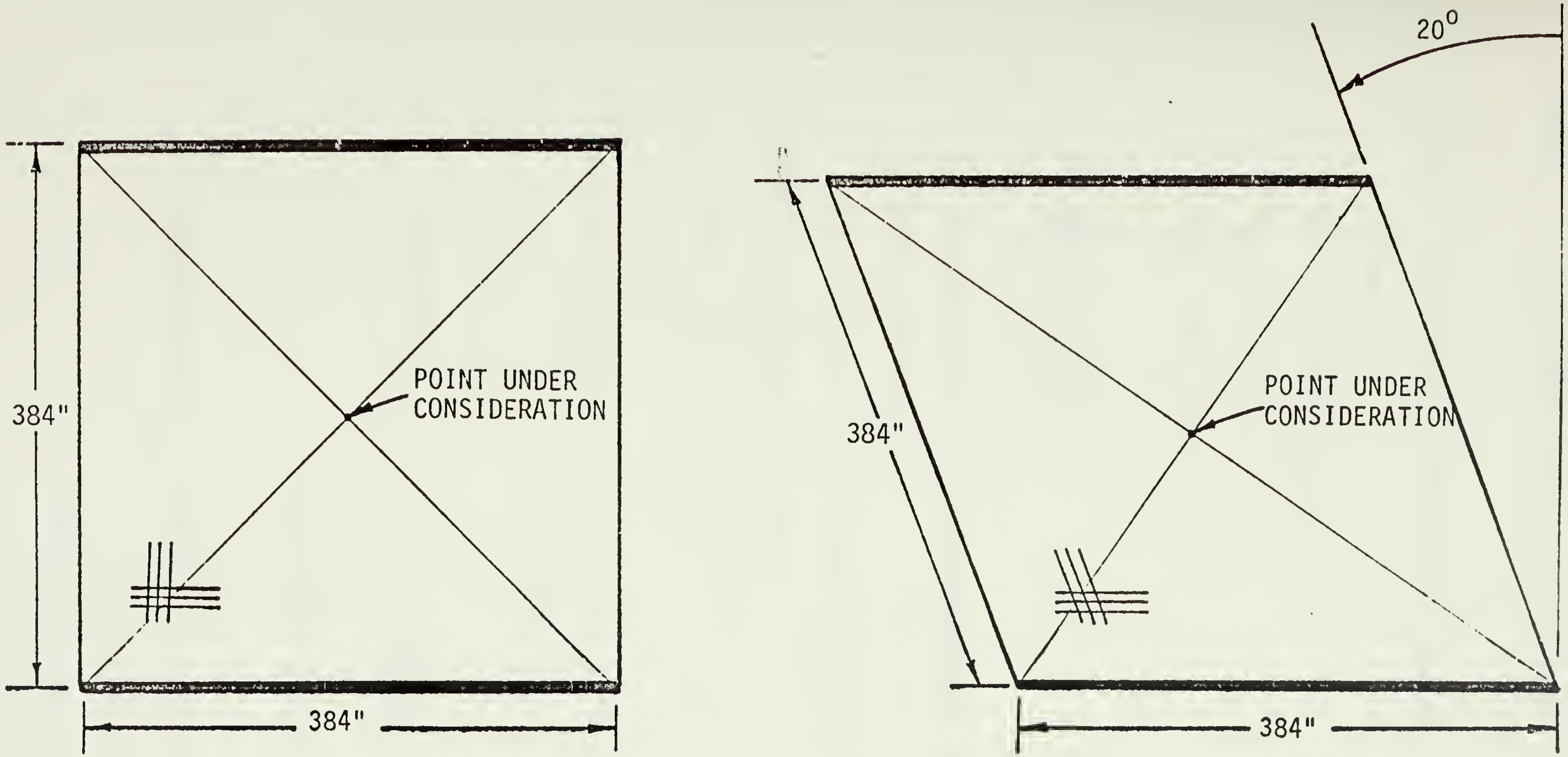
Deck thickness = 18.0 in
E = 3324 ksi
f_c' = 3401 psi
σ_c = 2891 psi
WSR = 1.00
σ_y = 50 ksi

In addition, the following equations from Morley [16] are common to all examples:

I. $$T_1 = \frac{1}{T_a}\left[a_{1x}\cos^2\theta + a_{1\phi}\sin^2(\theta - \phi)\right]$$

II. $$l_a = d_e + \left(\frac{T_2}{T_1}\right) d_o - \frac{(T_1 + T_2)^2}{2\,\sigma_c\,T_1}$$

III. $$a_{1x} = \sigma_y l_a A_{1x} \quad (x \leftrightarrow \phi)$$



(a) EXAMPLE 1-100 K CENTRAL LOAD
EXAMPLE 4-SU-4 PEAK LOAD

(b) EXAMPLE 2 - USING MOMENTS FROM EXAMPLE 1
EXAMPLE 3 - 100 K CENTRAL LOAD
EXAMPLE 5 - SU-4 PEAK LOAD

FIGURE 4.6 SKEWED REINFORCEMENT EXAMPLES

Example 1. Right deck 100 kip central load

Step (a) GTSTRUDL gives the following moments in the appropriate sign convention

$M_x = +28.49$ k-in/in

$M_y = +43.03$ k-in/in

$M_{xy} = 0.0$ k-in/in

(b) $\frac{M_x}{|M_{xy}|} = \frac{M_y}{|M_{xy}|} \rightarrow \infty$

(c) Using Figure 2 [16] the appropriate region is A

(d) From Table 1 [16]

$a_{2x} = a_{2y} = 0 \rightarrow$ No Top Steel Required

$a_{1x} = M_x + |M_{xy}| = 28.49$

$a_{1y} = M_y + |M_{xy}| = 43.03$

$\theta_s = -45°$

(e) From equation I, $T_1 = \frac{1}{l_a}[28.49 \cos^2(-45) + 43.03 \sin^2(-45)]$

$T_1 = 35.76/l_a$, $T_2 = 0$

From equation II, $l_a = 16 - \frac{T_1}{2(2.891)}$

or

$l_a{}^2 - 16\, l_a + 6.18 = 0 \rightarrow l_a = 15.60$

(f) From equation III, $12(28.49) = 50(15.60)A_{1x}$

$A_{1x} = 0.44$ in^2/ft

$12(43.03) = 50(15.60)A_{1y}$

$A_{1y} = 0.66$ in^2/ft

Example 2. 20 deg skew deck using moment triad of example 1

Step (a) $M_x = +28.49$ k-in/in

$M_y = +43.03$ k-in/in

$M_{xy} = 0.0$ k-in/in

(b) $$\frac{M_x}{|M_{xy}|} = \frac{M_y}{|M_{xy}|} \rightarrow \infty$$

(c) Using Figure 3 [16] the appropriate region is A2

(d) From Table 1 [16]

$a_{2x} = a_{2\phi} = 0 \rightarrow$ No Top Steel Required

$$a_{1x} = M_x = M_y \tan^2\phi + \frac{(1 + 2 \sin \phi)}{\cos\phi} [M_y \tan\phi - M_{xy} \approx$$

$$a_{1x} = 28.49 - 43.03(\tan 20)^2 + \frac{(1 + 2 \sin 20)}{\cos 20} [43.03 \tan 20 - 0 \approx$$

$$a_{1x} = 50.85$$

$$a_{1\phi} = \frac{M_y}{\cos^2\phi} + \frac{1}{\cos\phi} |M_y \tan\phi - M_{xy}|$$

$$a_{1\phi} = \frac{43.03}{(\cos 20)^2} + \frac{1}{\cos 20} |43.03 \tan 20 - 0|$$

$$a_{1\phi} = 65.36$$

$$\theta_s = \frac{1}{2}(90 + \phi)$$

$$\theta_s = +55^0$$

(e) From equation I, $T_1 = \frac{1}{l_a} [50.85 (\cos 20)^2 + 65.36 (\sin 35)^2 \approx$

$T_1 = 66.4/l_a$, $T_2 = 0$

From equation II, $l_a = 16 - \frac{T_1}{2(2.891)}$

or

$$l_a^2 - 16 l_a + 11.48 = 0$$

$$l_a = 15.25''$$

(f) From equation III, $12(50.85) = 50(15.25)\,A_{1x}$

$$A_{1x} = 0.80 \text{ in}^2/\text{ft}$$

$$12(65.36) = 50(15.25)A_{1\phi}$$

$$A_{1\phi} = 1.03 \text{ in}^2/\text{ft}$$

Comparison of this result with Example 1 illustrates the effects of 20 deg skew reinforcement minimized for the same moment triad. The total steel per unit width becomes (0.80 + 1.03) cos 20 = 1.72 in^2/ft or 56% more than Example 1.

Example 3. 20 deg skew deck 100 kip central load

Step (a) GTSTRUDL gives the following moments in the appropriate sign convention

$M_x = +\ 24.36$ k-in/in

$M_y = +\ 40.77$ k-in/in

$M_{xy} = +\ 0.646$ k-in/in

(b) $\dfrac{M_x}{|M_{xy}|} = \dfrac{24.36}{0.646} = 37.71 \qquad \dfrac{M_y}{|M_{xy}|} = \dfrac{40.77}{0.646} = 63.11$

(c) Using Figure 3 [16] the appropriate region is A2

(d) From Table 1 [16]

$a_{2x} = a_{2\phi} = 0 \rightarrow$ No top steel required

$$a_{1x} = M_x - M_y \tan^2\phi + \frac{(1 + 2\sin\phi)}{\cos\phi}\,[M_y \tan\phi - M_{xy}]$$

$$a_{1x} = 24.36 - 40.77\,(\tan 20)^2 + \left(\frac{1 + 2\sin 20}{\cos 20}\right)[40.77 \tan 20 - 0.646]$$

$$a_{1x} = 44.39$$

$$a_{1\phi} = \frac{M_y}{\cos^2} + \frac{1}{\cos\phi}\,|M_y \tan\phi - M_{xy}|$$

$$a_{1\phi} = \frac{40.77}{(\cos 20)^2} + \frac{1}{\cos 20} |40.77 \tan 20 - 0.646|$$

$$a_{1\phi} = 61.24$$

$$\theta_s = + \frac{1}{2} (90 + \phi)$$

$$\theta_s = + 55°$$

(e) From equation I, $T_1 = \frac{1}{l_a} [44.39 (\cos 55)^2 + 61.24(\sin 35)^2]$

$T_1 = 34.7/l_a$, $T_2 = 0$

From equation II, $l_a = 16 - \frac{T_1}{2(2.891)}$

or

$l_a^2 = -16l_a + 6.0 = 0$

$l_a = 15.62''$

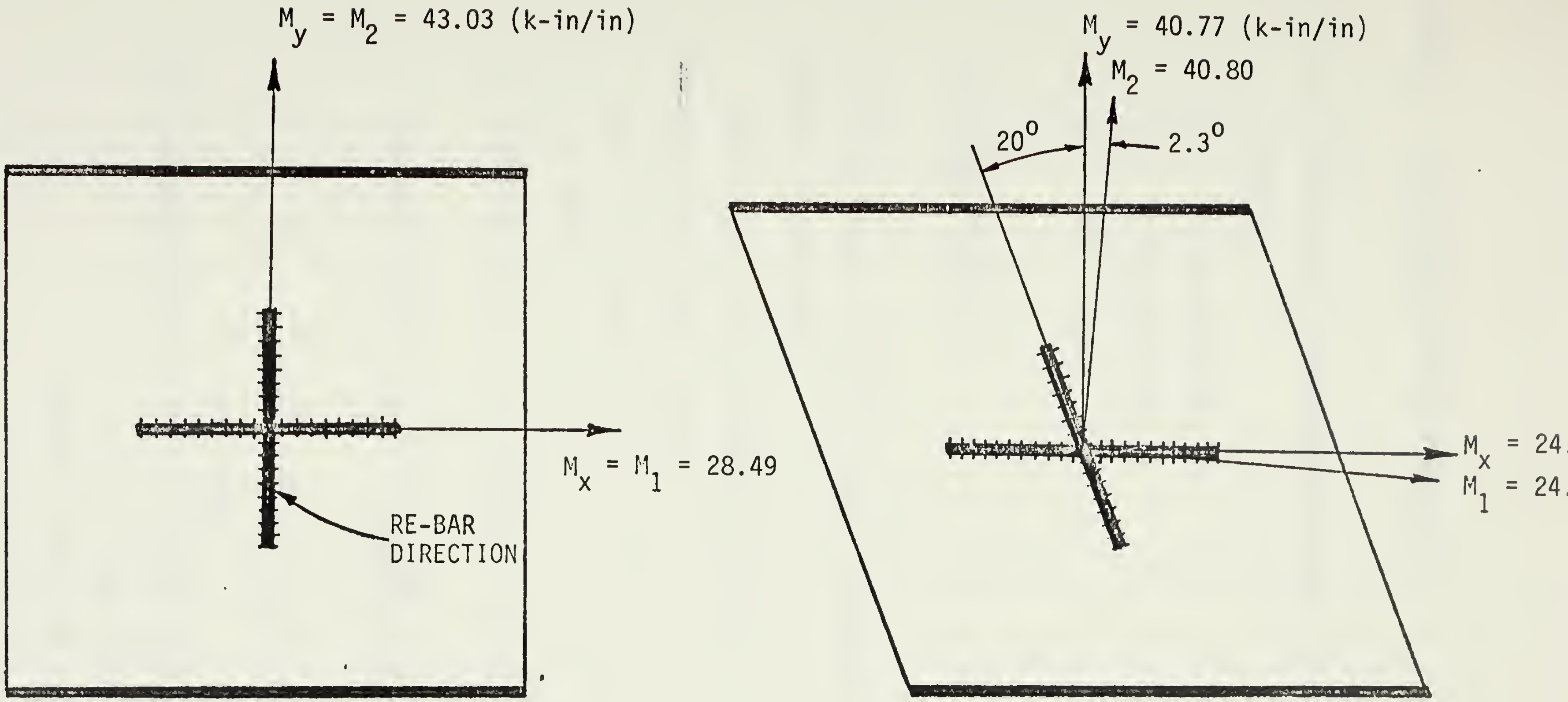
(f) From equation III, $12(44.39) = 50(15.62)A_{1x}$

$A_{1x} = 0.68 \text{ in}^2/\text{ft}$

$12(61.24) = 50(15.62)A_{1\phi}$

$A_{1\phi} = 0.94 \text{ in}^2/\text{ft}$

Comparison of this result with Example 1 illustrates the additional steel required at the geometric center for the 20 deg skew deck vs. the right deck, both under a central 100 kip load. The total steel per unit width becomes (0.68 + 0.94) cos 20 = 1.52 in^2/ft or 38% more than Example 1. This increase is due to the major principal moment lying within the obtuse angle of the reinforcement as shown in Figure 4.7.



(a) EXAMPLE 1 STEEL COINCIDES WITH PRINCIPAL MOMENTS

(b) EXAMPLE 3 LARGER PRINCIPAL LIES IN OBTUSE ANGLE BETWEEN RE-BARS. 38% MORE TOTAL STEEL IS REQUIRED OVER EXAMPLE 1

FIGURE 4.7 REINFORCEMENT EXAMPLES
100 KIP CENTRAL LOAD

Example 4. Right deck peak SU-4 loading

Step (a) GTSTRUDL gives the following moments in the appropriate sign convention

$M_x = + 5.07$ k-in/in

$M_y = + 13.90$ k-in/in

$M_{xy} = 0.0$ k-in/in

(b) $$\frac{M_x}{|M_{xy}|} = \frac{M_y}{|M_{xy}|} \rightarrow \infty$$

(c) Using Figure 2 [16] the appropriate region is A

(d) From Table 1 [16]

$a_{2x} = a_{2y} = 0 \rightarrow$ No Top Steel Required

$a_{1x} = M_x + |M_{xy}| = 5.07$

$a_{1y} = M_y + |M_{xy}| = 13.90$

$\theta_s = -45°$

(e) From equation I, $T_1 = 9.49/l_a$, $T_2 = 0$

From equation II, $$l_a = 16 - \frac{T_1}{2(2.891)}$$

or

$l_a^2 = -16 l_a = 1.64 = 0$

$l_a = 15.90''$

(f) From equation III, $12(5.07) = 50(15.90)A_{1x}$

$A_{1x} = 0.08$ in^2/ft

$12(13.90) = 50(15.90)A_{1y}$

$A_{1y} = 0.21$ in^2/ft

Example 5. 20 deg skew deck peak SU-4 loading

Step (a) GTSTRUDL gives the following moments in the appropriate sign convention

$M_x = +4.66$ k-in/in

$M_y = +13.13$ k-in/in

$M_{xy} = -0.36$ k-in/in

(b) $\frac{M_x}{|M_{xy}|} = \frac{4.66}{0.36} = 12.9 \qquad \frac{M_y}{|M_{xy}|} = \frac{13.13}{0.36} = 36.5$

(c) Using Figure 3 [16] and noting that $M_{xy} < 0$

$$M_x \rightarrow -4.66 \ , \ M_y \rightarrow -13.13$$

and the appropriate region is B

(d) From Table 1 [16] with suffixes 1, 2, s, h interchanged

$a_{2x} = a_{2\phi} = 0 \rightarrow$ No Top Steel Required

$$a_{1x} = -M_x + M_y \tan^2\phi - \frac{(1 + 2 \sin \phi)}{\cos \phi} [M_y \tan \phi - M_{xy}]$$

$$a_{1x} = 4.66 - 13.13 (\tan 20)^2 - \frac{(1 + 2 \sin 20)}{\cos 20} [-13.13 \tan 20 + 0.36]$$

$$a_{1x} = 10.84$$

$$a_{1\phi} = \frac{M_y}{\cos^2\phi} + \frac{1}{\cos \phi} |M_y \tan \phi - M_{xy}|$$

$$a_{1\phi} = \frac{13.13}{(\cos 20)^2} + \frac{1}{\cos 20} |-13.13 \tan 20 + 0.36|$$

$$a_{1\phi} = 19.57$$

$$\theta_s = + \frac{1}{2} (90 + \phi) = 55^0$$

(e) From equation I, $T_1 = \frac{1}{l_a}[10.84\ (\cos 20)^2 + 19.57\ (\sin 35)^2]$

$T_1 = 16.0/l_a,\ T_2 = 0$

From equation II, $l_a = 16 - \frac{T_1}{2(2.891)}$

or

$l_a^2 - 16l_a + 2.77 = 0 \rightarrow l_a = 15.82$

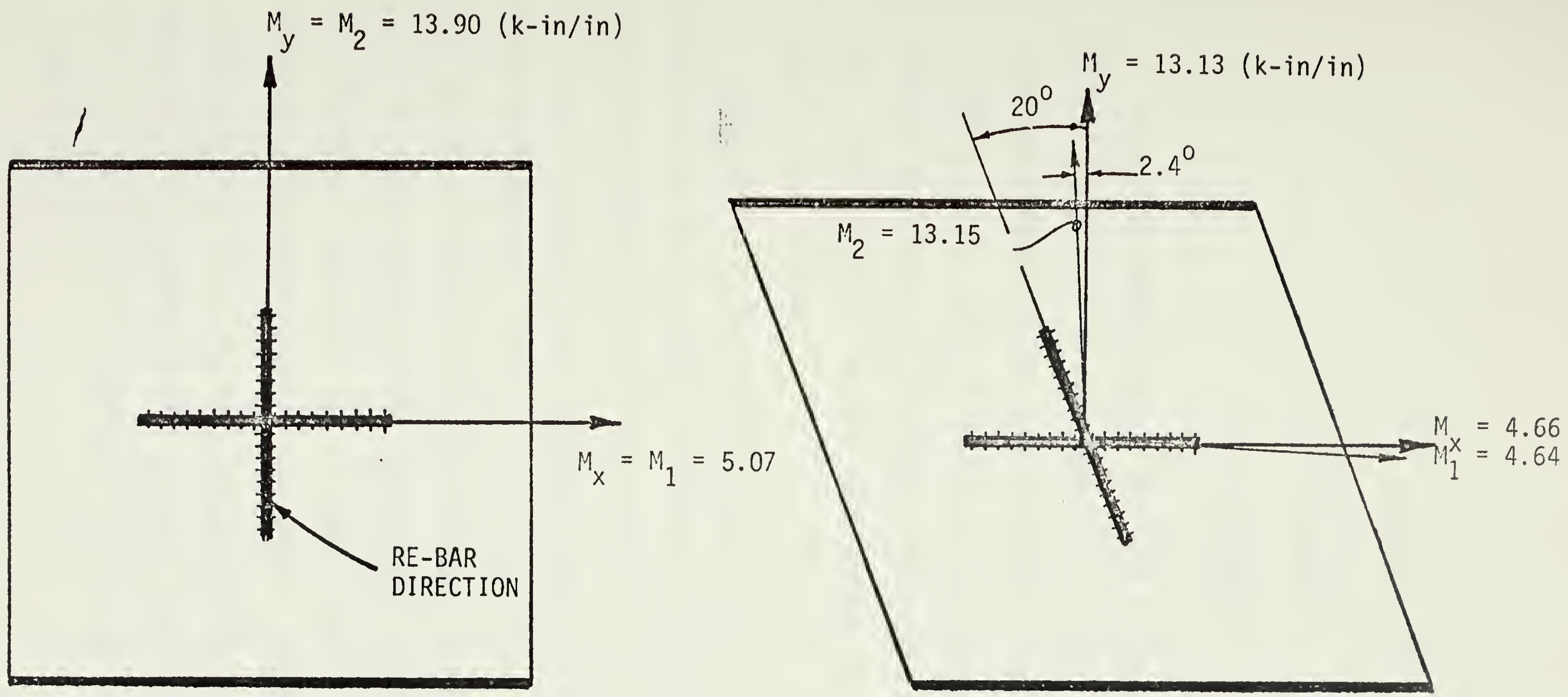
(f) From equation III, $12(10.84) = 50(15.82)A_{1x}$

$A_{1x} = 0.16\ \text{in}^2/\text{ft}$

$12(19.57) = 50(15.82)A_{1\phi}$

$A_{1\phi} = 0.30\ \text{in}^2/\text{ft}$

Comparison of this result with Example 4 illustrates the additional steel required at the geometric center for the 20 deg skew deck vs. the right deck, both under peak SU-4 loading. The total steel per unit width becomes (0.16 + 0.30) cos 20 = 0.43 in^2/ft or 49% more than Example 4. This increase is again due to the major principal moment lying in the obtuse corner of the reinforcement as shown in Figure 4.8.



(a) EXAMPLE 4 STEEL COINCIDES WITH PRINCIPAL MOMENTS

(b) EXAMPLE 5 LARGER PRINCIPAL LIES IN THE OBTUSE ANGLE BETWEEN THE RE-BARS. 49% MORE TOTAL STEEL IS REQUIRED OVER EXAMPLE 4

FIGURE 4.8 REINFORCEMENT EXAMPLES PEAK SU-4 LOADING

CHAPTER 5

CONCLUSIONS

5.1 Summary

The finite element method was used to examine the effects of skew angle on the major principal moments of simple spans. A mesh size of eight span elements in 30 feet was found to give results within about 6% of those found from a more intricate localized mesh surrounding a more realistic tire load. These results varied little with change in aspect ratio. This mesh size was therefore chosen as a guide for the parameter studies which followed.

Skew angles of 0, 20 and 40 degrees were investigated for various width to span ratios (WSR's) as shown in Figure 3.1. The major principal moments at key points in the deck were examined as an FDOT SU-4 type truck was moved across the span. The service load simulator program of Appendix A was used to calculate the equivalent nodal forces for the truck in any position on the skewed deck. The results showed that for center loading, peak moment reductions of up to 24% were found for 40 degree skew decks over orthogonal decks. The percent reductions were lower for smaller WSR's. In general, the major principal moments peaked earlier (i.e., at lesser advanced positions of the truck along the span) for increased angles of skew. This can be attributed to the fact that the wheels of the axles do not reach span center simultaneously.

The direction of reinforcement plays an important role in the flexural behavior of the deck [2]. Orthogonal reinforcement laid parallel to the supports provides for a stiffer slab which behaves well under service loads. Orthogonal reinforcement laid parallel to the free edges provides a more flexible slab. However, skewed reinforcement is the preferred method from the construction point of view. The affine deck method discussed in section 4.2 seems to be the most practical for use in the design office. Morely's [16] method for minimum steel at a point would seem to have limitations in practice, although it serves well to illustrate the considerable effect that the direction of the major principal moment has on the quantity of skewed steel required.

5.2 Further Study

More extensive parameter studies could be used with different truck types and combination loading. Program SKEW LOADER (Appendix A) could be easily modified for this application. In addition, the effects of girders, deck thickness and material properties could also be studied. The reinforcement design method developed by Morely [16] is well suited to computer programming. This could be an area of further study along with complete design examples and comparison with the affine deck method.

The stress concentration effect at the obtuse corners could be investigated by the finite element method. This could be of particular importance as experiments have shown that this is often the area of initial failure. An extremely fine local mesh could be assembled (such as along the line of Figure 2.6) in the area of the obtuse corner and the moments investigated with variation in deck angle of skew.

APPENDIX A

PROGRAM SKEW LOADER

APPENDIX A

PROGRAM SKEW LOADER

A.1 Introduction

Since the parameter study calls for moving a truck incrementally across a skewed deck and evaluating the moments for each truck position, a method had to be developed for loading the deck. GTSTRUDL allows for concentrated loads to be placed only at the nodal points of the mesh. Thus the weight of each truck wheel within an element must be broken into its statically equivalent nodal forces before it can be input to GTSTRUDL for stiffness analysis. To do this by hand would be extremely tedious as 4 reactions would have to be calculated for each of 8 wheels for 170 different load cases. Furthermore, the positions of the wheels in relation to the mesh nodes are geometrically complex making large numbers of calculations prohibitive. This type of problem is therefore well suited to computer programming.

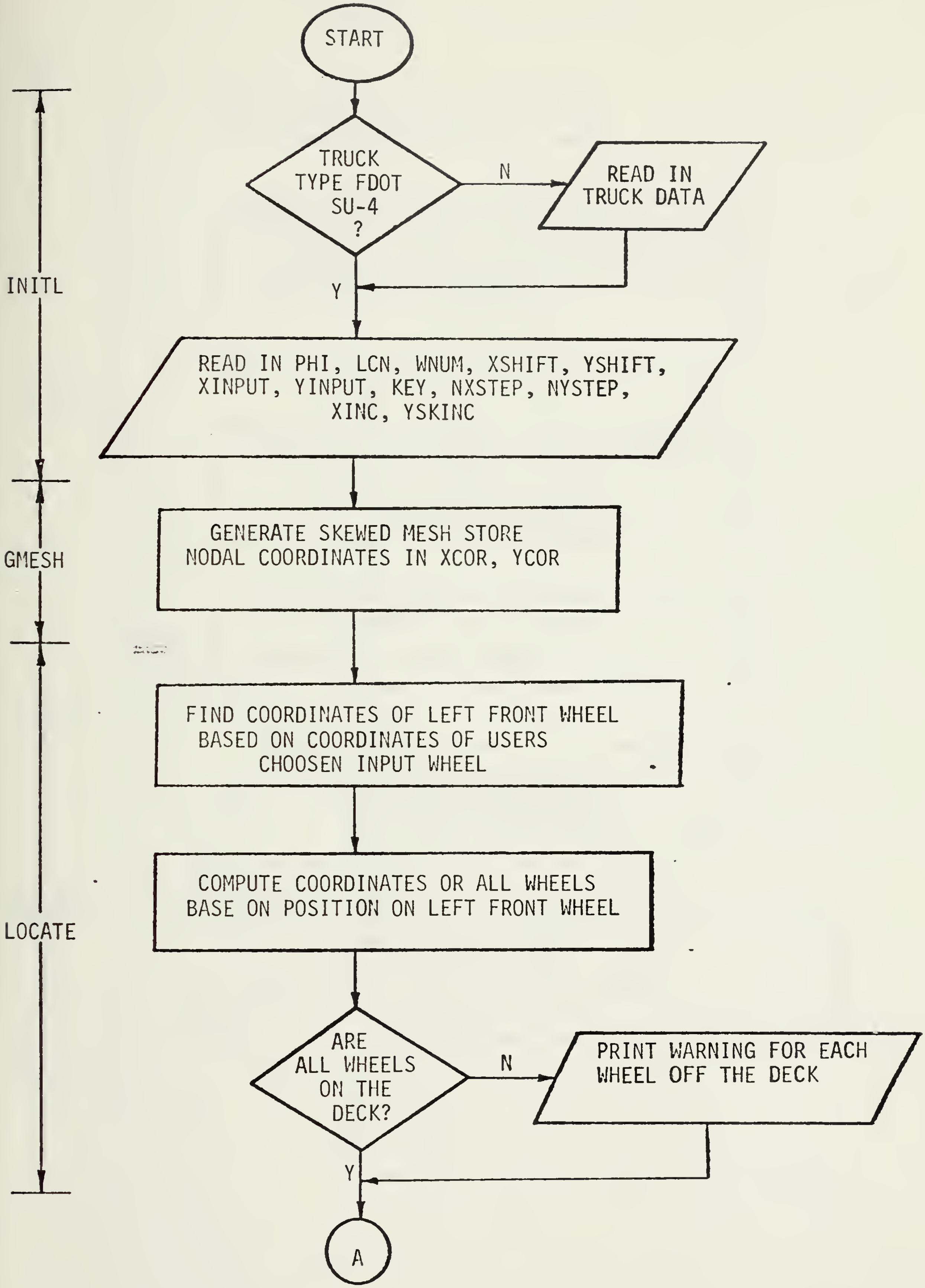
Program SKEW LOADER was developed to output the equivalent nodal forces for a truck positioned on a skewed deck. The program will generate any mesh size on a deck of any dimensions at any angle of skew. The data for the truck FDOT SU-4 is stored internally in the program. Although any type of truck may be used if the truck width, axle spacing and axle weights are known. The user also has the option of specifying the truck position in rectangular or skewed coordinates. The latter is recommended for most applications and in general greatly simplifies the input procedure. The position of any wheel may be input to establish the truck position, which is always assumed to lie parallel to the left

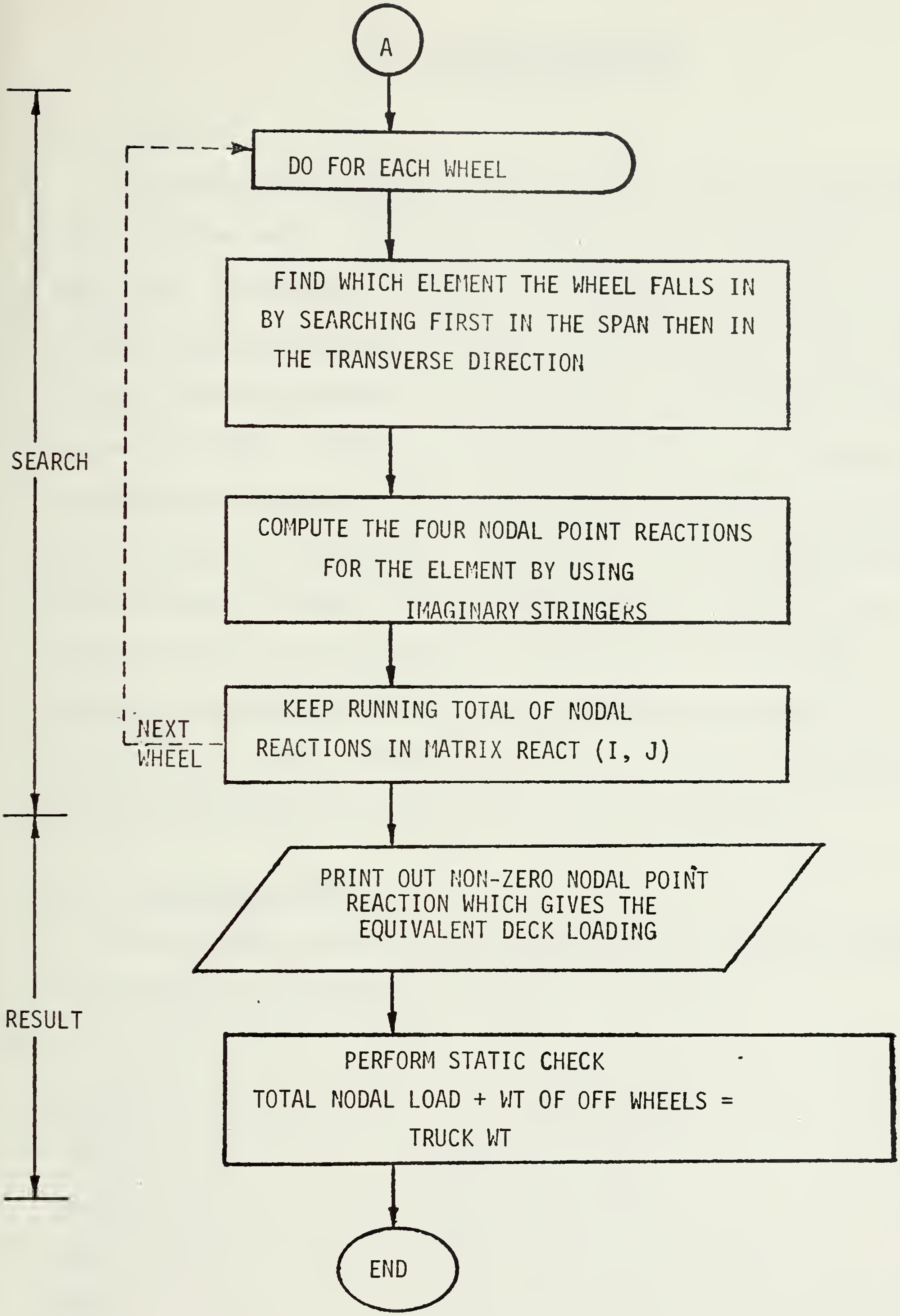
and right edges of the deck. The program uses the stringer method with each loaded element to solve for the equivalent nodal forces.

A set command and regeneration programs were also written to expedite the study. These programs were used to operate on the first GTSTRUDL program by rewriting the joint load input portion based on the output of SKEW LOADER. In this way the truck could be repositioned automatically and sent back to GTSTRUDL quasi-interactively. This provided for an orderly and systematic approach to data acquisition. This program set was written in command language on a VAX 11-750 computer. The program SKEW LOADER is written in FORTRAN-77.

The rest of Appendix A gives a flowchart, program description and input guide for SKEW LOADER. Copies of the program are also included along with two examples and sample outputs.

A.2 FLOWCHART


START
TRUCK TYPE FDOT SU-4 ?
N
READ IN TRUCK DATA
Y
READ IN PHI, LCN, WNUM, XSHIFT, YSHIFT, XINPUT, YINPUT, KEY, NXSTEP, NYSTEP, XINC, YSKINC
GENERATE SKEWED MESH STORE NODAL COORDINATES IN XCOR, YCOR
FIND COORDINATES OF LEFT FRONT WHEEL BASED ON COORDINATES OF USERS CHOOSEN INPUT WHEEL
COMPUTE COORDINATES OR ALL WHEELS BASE ON POSITION ON LEFT FRONT WHEEL
ARE ALL WHEELS ON THE DECK?
N
PRINT WARNING FOR EACH WHEEL OFF THE DECK
Y
A
INITL
GMESH
LOCATE


A
DO FOR EACH WHEEL
FIND WHICH ELEMENT THE WHEEL FALLS IN BY SEARCHING FIRST IN THE SPAN THEN IN THE TRANSVERSE DIRECTION
COMPUTE THE FOUR NODAL POINT REACTIONS FOR THE ELEMENT BY USING IMAGINARY STRINGERS
KEEP RUNNING TOTAL OF NODAL REACTIONS IN MATRIX REACT (I, J)
NEXT WHEEL
PRINT OUT NON-ZERO NODAL POINT REACTION WHICH GIVES THE EQUIVALENT DECK LOADING
PERFORM STATIC CHECK
TOTAL NODAL LOAD + WT OF OFF WHEELS = TRUCK WT
END
SEARCH
RESULT

A.3 Program Description

A.3.1 Main

The program SKEW LOADER is structured as a series of subroutine calls from the main. The initial matrix sizes are dimensioned arbitrarily in the opening statement allowing for a maximum mesh size of 30 nodes each way and a maximum truck size of 18 wheels. These numbers are only set for convenience so that variably dimensioned subroutines can be used later. Therefore the maximums above can be increased easily by adjusting the sizes in the opening dimension statement (no other program changes are required). The input is read from LOADER.DAT and the output goes to OUTPUT.LIS. Only the key subroutines will be discussed below as the functions of the others are self evident. The subroutine descriptions below contain a complete listing of the variables used within. Variables which are not listed are defined within the subroutine in terms of the ones described here.

A.3.2 Subroutine INITL

This is where most of the user supplied data is read in, stored and echo printed. The following variables are used here:

VARIABLE	DESCRIPTION
AXLSP	Axle spacing matrix
AXLWT	Axle weight matrix
DDX	Deck dimension along X-axis
DDYSK	Deck dimension along Y (skew)-axis
ERR	Error switch
KEY	Mesh print request switch

VARIABLE	DESCRIPTION
LCN	Load case number
NA	Number of axles
NAXLSP	Number of axle spaces
NW	Number of wheels
NXCROS	Number of crossings (mesh lines) X direction
NXSTEP	Number of steps (elements) X direction
PHI	Angle of deck skew
TRTYPE	Truck type (SU-4 or custom)
WIDTH	Width of truck
WJX	X coordinate of user's input wheel
WJY	Y coordinate of user's input wheel
WNUM	Input wheel number
WT	Wheel weight number
XINC	Increment (element size) X-axis
XSKINC	Increment (element size) Y (skew)-axis
XSHIFT	Shift coordinate switch X-axis
YSHIFT	Shift coordinate switch Y-axis

A.3.3 Subroutine GMESH

The mesh is generated here based on the user inputs specified in INITL. The nodes are generated first in the span direction and then along the X-axis. The coordinates of each node are stored in column vectors XCOR and YCOR. The following variables are used here:

VARIABLE	DESCRIPTION
ERR	Error switch
KEY	Mesh print request switch
NXCROS	Number of crossings (mesh lines) X direction
NXSTEP	Number of steps (elements) X direction
NYCROS	Number of crossings (mesh lines) Y direction
NYSTEP	Number of steps (elements) Y direction
PHI	Angle of deck skew
XCOR	Nodal X coordinate storage matrix
XINC	Increment (element size) X-axis
YCOR	Nodal Y coordinate storage matrix
YSKINC	Increment (element size) Y (skew)-axis

A.3.4 Subroutine LOCATE

Now that the position of one of the truck wheels is known (user's input) the rest can be determined assuming that the truck is lying along the span direction (i.e., parallel to the deck's free edges). From trigonometry the position of the left front wheel can be found from the known position of the input wheel. Then a standard procedure can be followed to locate all wheels relative to this position by geometry. It may often occur that one or more of the truck wheels are lying outside the boundary of the deck. In this case a warning is printed to show the user that the total weight of the truck is not on the deck. This must be taken into account in the statics check at the end of the program.

The following variables are used in LOCATE:

VARIABLE	DESCRIPTION
AXLSP	Axle spacing matrix
DDX	Deck dimension along X-axis
DDYSK	Deck dimension along Y (skew)-axis
ERR	Error swtich
NA	Number of axis
NAXLSP	Number of axle spaces
NW	Number of wheels
NXCROS	Number of crossing (mesh lines) X direction
NYCROS	Number of crossing (mesh lines) Y direction
OFFWT	Matrix containing weights of wheels off deck
PHI	Angle of deck skew
PSD	Perpendicular support distance
REACT	Matrix of nodal reactions
USERX	X input (carried)
USERY	Y input (carried)
WHEELX	X coordinate of wheel under consideration
WHEELY	Y coordinate of wheel under consideration
WIDTH	Truck width
WJX	X coordinate of user's input wheel
WJY	Y coordinate of user's input wheel
WT	Matrix of wheel weights
W1X	X coordinate of wheel #1
W1Y	Y coordinate of wheel #1
XSHIFT	Shift coordinate switch X-axis
YSHIFT	Shift coordiante switch Y-axis

3.5 Subroutine SEARCH

This subroutine is the heart of the program and certainly the most complex. The function here is to find the location of each wheel with respect to its surrounding nodes, then compute the nodal point reactions by the stringer method. For a right angle deck the search is a relatively

simple procedure as the nodal coordinates can be easily compared to the coordiantes of the wheel. The skewed deck however, provides for complications in locating the position of the wheel relative to its neighboring nodes as a series of offsets from the edge of the skewed element must be computed and compared. The idea is to first search the span direction for the first node with a Y coordinate larger than the Y coordinate of the wheel. Calling the Y coordinate of this node and the one immediately below it D1 and D2, respectively, the lower "track" D2 can then be searched. Now the first node along this track with an X coordinate larger than the X coordinate of the wheel is noted. The X coordinate of this node is called CHECK1. Now the X offset distance of the wheel from the element edge is examined to see on which side of the line it falls (see Figure A.1). If XOFF1 is greater than WXOFF1 the wheel is in the element on the right. If it is less than WXOFF1 then it is in the element on the left. If the two distances are equal then it is on the element edge. A similar procedure is used to locate the neighboring nodes above the wheel (i.e., on upper track D1). Provisions are made for cases in which the wheel falls directly on a node or on an element edge.

Now that the coordinates of the four neighboring nodes are known, the distances to the wheel can be easily computed. An immaginary grid of stringers is laid on the element as follows:

1. One is positioned under the wheel and laid horizontally just reaching the element edges
2. Then two more are laid under the first along the skewed edges

The reactions of the four corners from the weight of the wheel are then computed by statics and a running total of the results is kept in a storage matrix for the mesh called REACT. The following variables are used in subroutine SEARCH:

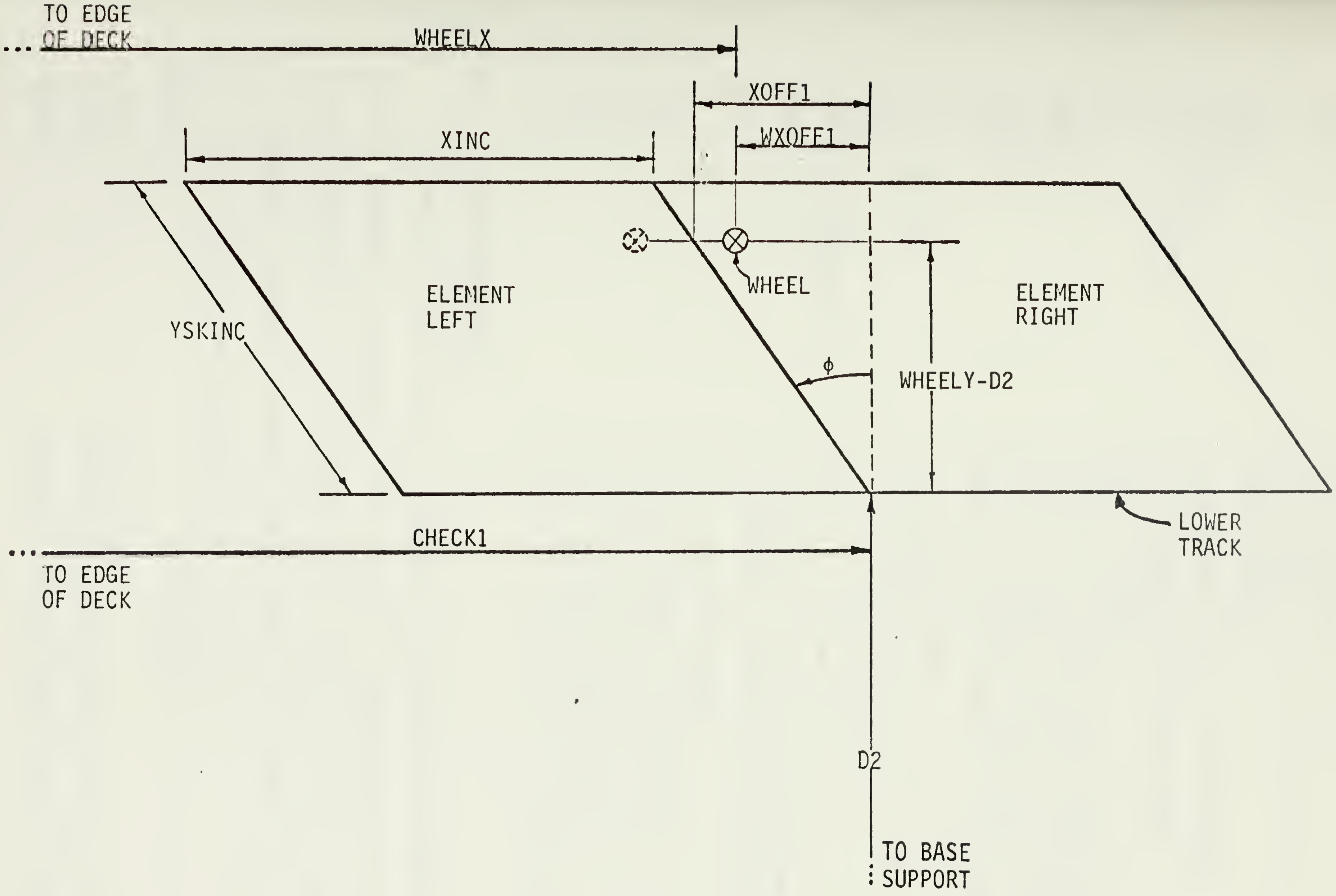


FIGURE A.1 SUBROUTINE "SEARCH" LOWER TRACK

VARIABLE	DESCRIPTION
I,L,N	Node counters
K	Wheel counter
LCOUNT	Element counter
NA,NB,NE,NW	Nodes above, below, east and west
NNE,NNW,NSE,NSW	Node northeast, northwest, etc.
NW	Number of wheels
NXCROS	Number of crossings (mesh lines) X direction
NXSTEP	Number of steps (elements) X direction
NYCROS	Number of crossings (mesh lines) Y direction
NYSTEP	Number of steps (elements) Y direction
PHI	Angle of deck skew
RA,RB,RL, RR	Reaction above, below, left, right
REACT	Matrix of nodal reactions
RNNE,RNNW,RNSE,RNSW	Reactions node northeast, etc.
WHEELX	X coordinate of wheel under consideration
WHEELY	Y coordinate of wheel under consideration
WT	Matrix of wheel weights
XCOR	Nodal coordinate storage matrix
XINC	Increment (element size) X-axis
YCOR	Nodal coordinate storage matrix
YSKINC	Increment (element size) Y (skew)-axis

A.3.5 Subroutine RESULT

The non-zero nodal reactions obtained from subroutine SEARCH are printed out here and summed to check statics. The weight of the truck is checked against the sum of the total load on the deck and the weight of the "off wheels". The user can verify this result to be the original weight of the truck. The following variables are used here:

VARIABLE	DESCRIPTION
NCOUNT	Node counter
NXCROS	Number of crossing (mesh lines) X direction
NYCROS	Number of crossing (mesh lines) Y direction

OFFWT	Total weight of wheels off the deck
REACT	Matrix of nodal reactions
TOTAL	Running sum of reactions for statics check
TRKWT	Back summed weight of truck
USERX	X input (carried)
USERY	Y input (carried)
WJX	X coordinate of user's input wheel
WJY	Y coordinate of user's input wheel
WNUM	Input wheel number (user's choice)
XSHIFT	Shift coordinate switch X-axis
YSHIFT	Shift coordinate switch Y-axis

A.4 Input Guide

A.4.1 Data deck

The data file must be titled LOADER.DAT and be accessible from the main. The following data must be input in the order shown beginning in column #1. The term "card" refers to one line of data in the file.

CARD	FORMAT	DESCRIPTION
1	Free	Alpha-numeric title of output
2	1I1	Enter truck type as follows (a) 1 is FDOT SU-4 (b) 9 is custom*
3	1F10.1	Angle of deck skew (degrees)
4	1I2	Load case number (user's option)
5	1I2	Input wheel number
6	1I1	XSHIFT switch (a) 1 is on (b) 0 is off

7	1I1	YSHIFT switch (a) 1 is on (b) 0 is off
8	1F7.2	X input for wheel given on card #5 above as follows: (a) if XSHIFT is on, give the X distance of the wheel from the left skewed edge of the deck (b) if the XSHIFT is off, give the X coordinate of the wheel
9	1F7.2	Y input for wheel given on card #5 above as follows: (a) If YSHIFT is on, give the distance to the wheel as measured along the inclined span edge for the base support (b) if YSHIFT is off, give the Y coordinate of that wheel
10	1I1	Mesh print request switch (a) 1 is yes (b) 0 is no
11	1I2	Number of elements in the X direction
12	1I2	Number of elements along the Y (skewed) direction
13	1F6.2	Element size X direction
14	1F6.2	Element size Y (skewed) direction

*Note: If the custom option is chosen, then the following data must be entered on the next data cards (i.e., after card #2):

(a) Number of axles [format 1I1]

(b) Truck width [format 1F6.2]

(c) Spacing for each successive axle as measured from the previous axle (one per data card) [format 1F6.2]

(d) Axle weights (one per data card) [format 1F6.2]

A.4.2 Examples

The above proceure is illustrated by two examples. The first is an input to SKEW LOADER for the SU-4 case, and the second is for the custom option. Figures A.2 through A.5 given the input data and resulting truck position diagrams for the two cases. Comments are provided on the sample inputs for clarity.

A.5 Extension of the Program

The program can be easily extended to include a number of standard truck types beyond the SU-4. The easiest way would be to write more subroutines in the form of TRTYPE1 to include data for any trucks. Then of course modify the switches in subroutine INITL. The program could also be easily extended to include more than one truck on the deck at a time. Finally, a more sophisticated mech generator could be included to allow for elements of different dimensions. This feature would be particularly useful in the analysis decks with stiffening girders.

C FOR COMMENT

STATEMENT NUMBER 1 5	Cont. 6	INPUT 7	COMMENTS 72
SKEW		LOADER EXAMPLE 1 (SU-4)	ALPHA-NUMIC TITLE
1			TRUCK TYPE FDOT SU-4
40.0			ANGLE OF DECK SKEW 40 DEGREES
1			LOAD CASE #1 (USER'S OPTION)
5			INPUT WHEEL IS #5
1			THE XSHIFT IS ON
1			THE YSHIFT IS ON
192.0			WHEEL #5 IS PLACED 192" FROM LEFT EDGE
240.0			WHEEL #5 IS PLACED 240" FM BASE SUPPORT
0			KEY=0 MESH WILL NOT BE PRINTED
12			12 ELEMENTS IN X DIRECTION
8			8 ELEMENTS IN SPAN DIRECTION
48.0			48" ELEMENT SIZE IN X DIRECTION
48.0			48" ELEMENT SIZE IN Y (SKEW) DIRECTION

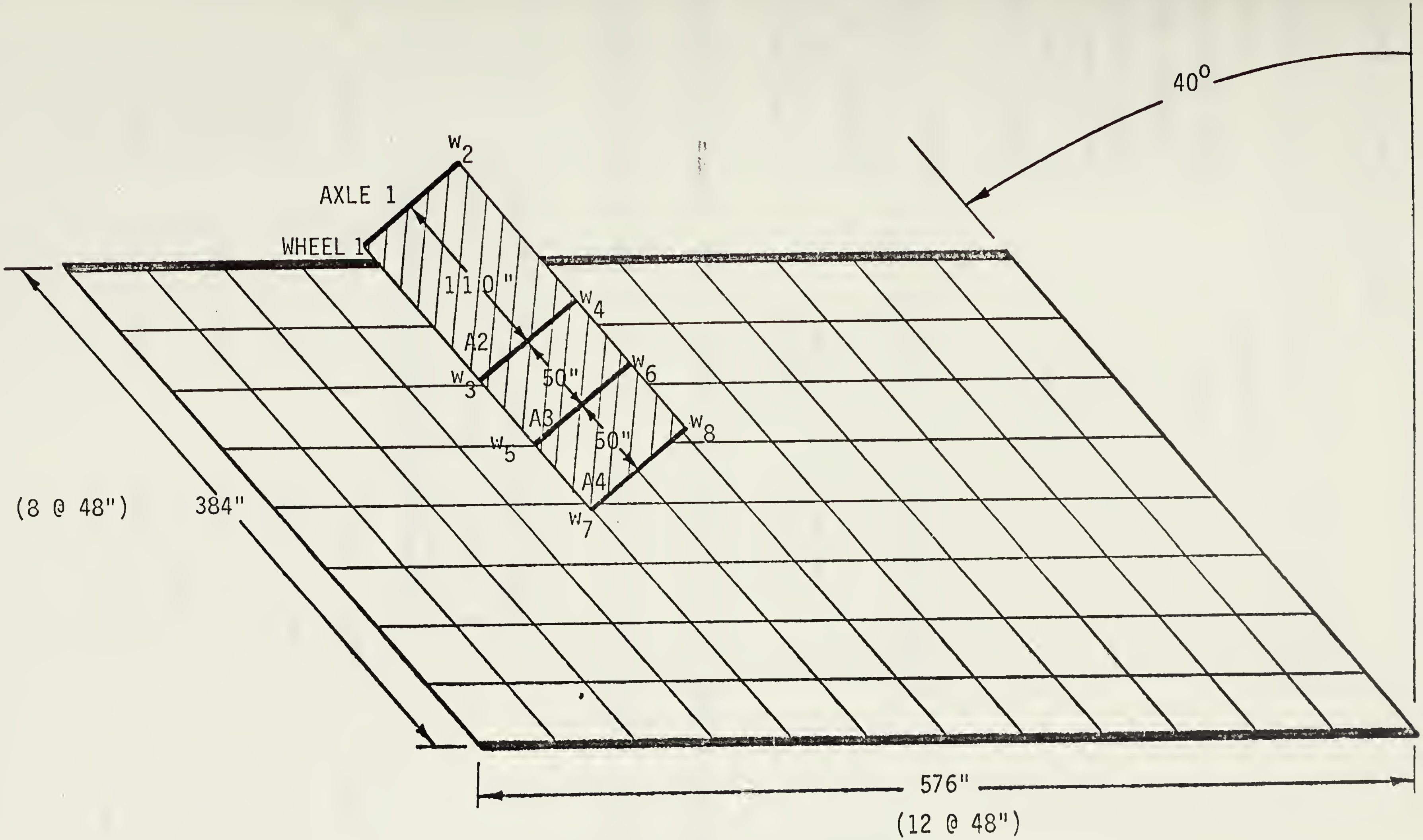


FIGURE A.3 SKEW LOADER EXAMPLE 1 (SU-4)

```
J LOADER EXAMPLE 1 (SU-4)

----------------------------------------------
JT CHECK
----------------------------------------------

K TYPE                     FDOT SU-4
E OF SKEW (DEG)              40.0
) CASE NUMBER                 1
JT WHEEL NUMBER               5
NPUT (SHIFT ON)             192.00
NPUT (SHIFT ON)             240.00
H PRINT REQUEST              NO


--------------------------------------------------
H DATA                 X-AXIS      Y-AXIS (SKEWED)
--------------------------------------------------

BER OF ELEMENTS          12            8
MENT SIZE               48.00        48.00
K DIMENSION            576.00       384.00

*WARNING**** WHEEL #  1 IS OFF THE DECK TO THE NORTH ****WARNING****

*WARNING**** WHEEL #  2 IS OFF THE DECK TO THE NORTH ****WARNING****


              ******************************
              ******************************
              *                            *
              * RESULTS OF LATEST ANALYSIS *
              *                            *
              ******************************
              ******************************

EEL #   WEIGHT   IN ELEMENT #   AFFECTING NODES   X COORD     Y COORD

3        9.35     RT OF 31        ONLY 43 44         5.59      222.15
4        9.35         56        62 63 71 72         63.81      271.00
5        9.35     ABOVE 29        ONLY 42           37.73      183.85
6        9.35         55        61 62 70 71         95.95      232.70
7        9.35     RT OF 28        ONLY 40 41        69.87      145.55
8        9.35         54        60 61 69 70        128.09      194.40
```

```
ULTANT NODAL LOADS
E #      LOAD (KIPS)

              0.39
              8.96
              9.35
              8.96
              0.39
              6.22
              8.36
              8.36
              3.23
              0.45
              0.60
              0.60
              0.23


TICS CHECK
AL LOAD ON DECK = 56.10 KIPS
CK WEIGHT = 70.00 KIPS

*NOTE****
CE THE XSHIFT IS ON X INPUT OF 192.00 GIVES X COORD   37.73

*NOTE****
CE THE YSHIFT IS ON Y INPUT OF 240.00 GIVES Y COORD  183.85
```

STATEMENT NUMBER 1 5	Cont. 6	7 INPUT	COMMENTS 72
SKEW		LOADER EXAMPLE 2 (CUSTOM)	ALPHA-NUMERIC TITLE
9			TRUCK TYPE CUSTOM (HS20-44 USED HERE)
3			3 AXLES
72.0			TRUCK WIDTH
168.0			DISTANCE BETWEEN AXLES 1 AND 2
192.0			DISTANCE BETWEEN AXLES 2 AND 3
8.0			AXLE 1 IS 8 KIPS
32.0			AXLE 2 IS 32 KIPS
32.0			AXLE 3 IS 32 KIPS
30.0			ANGLE OF DECK SKEW IS 30 DEGREES
1			LOAD CASE #1 (USER'S OPTION)
3			INPUT WHEEL IS #3
1			THE XSHIFT IS ON
1			THE YSHIFT IS ON
72.0			WHEEL #3 IS PLACED 72" FROM LEFT EDGE
192.0			WHEEL #3 IS PLACED 192" FM BASE SUPPORT
0			KEY=0 MESH WILL NOT BE PRINTED
12			12 ELEMENTS IN THE X DIRECTION
15			15 ELEMENTS IN THE SPAN DIRECTION
36.0			36" ELEMENT SIZE IN X DIRECTION
24.0			24" ELEMENT SIZE IN Y (SKEW) DIRECTION

FIGURE A. 4 EXAMPLE 2 INPUT

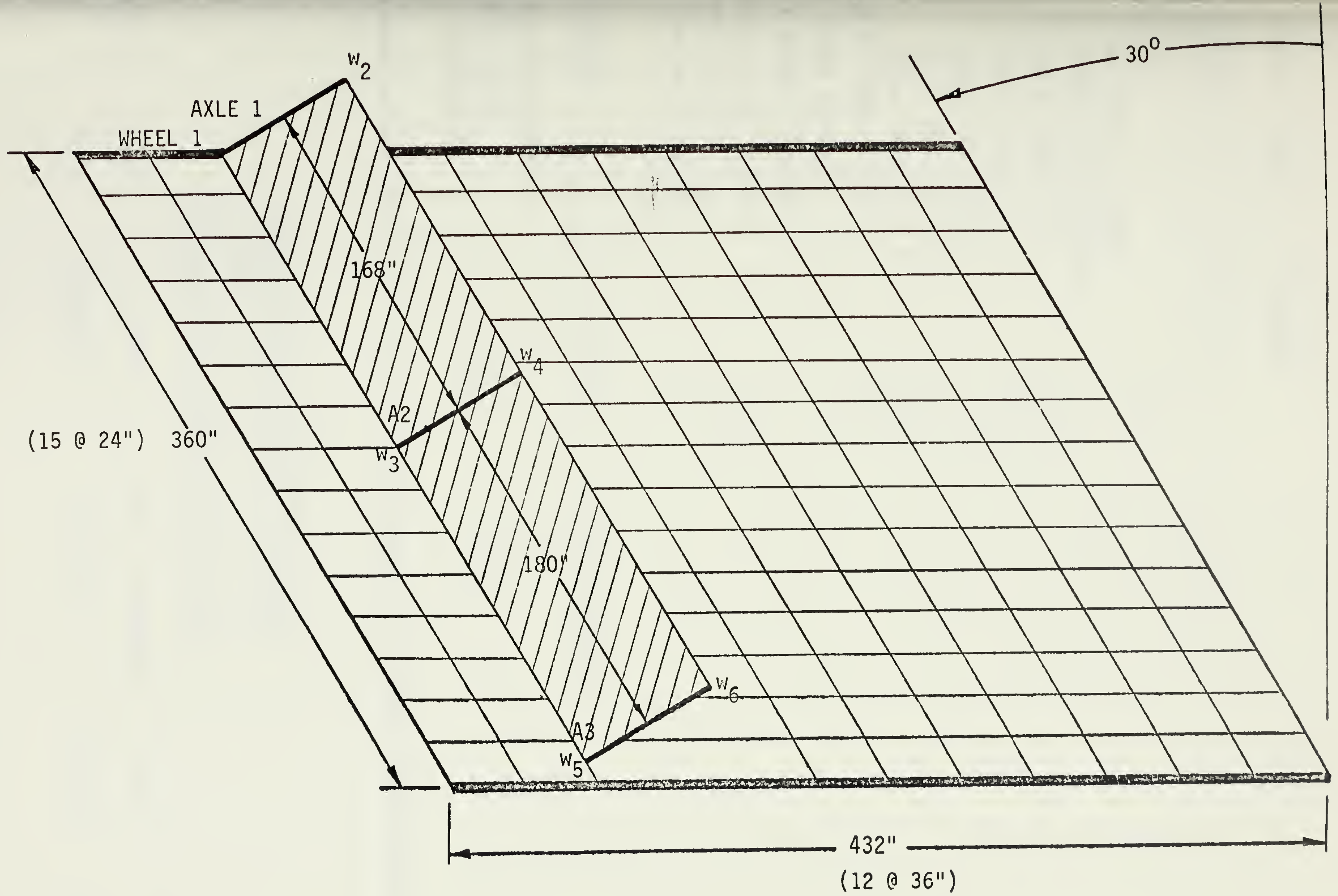


FIGURE A.5 SKEW LOADER EXAMPLE 2 (CUSTOM TRUCK)

```
 LOADER EXAMPLE 2 (CUSTOM)

----------------------------------------------
IT CHECK
----------------------------------------------
K TYPE                     CUSTOM
   NUMBER OF AXLES            3
   TRUCK AXLE WIDTH          72.00
   AXLE SPACE # 1           168.00
   AXLE SPACE # 2           180.00
   AXLE WEIGHT # 1            8.00
   AXLE WEIGHT # 2           32.00
   AXLE WEIGHT # 3           32.00
LE OF SKEW (DEG)             30.0
) CASE NUMBER                 1
JT WHEEL NUMBER               3
IPUT (SHIFT ON)              72.00
IPUT (SHIFT ON)             192.00
H PRINT REQUEST              NO


--------------------------------------------------
H DATA                 X-AXIS      Y-AXIS (SKEWED)
--------------------------------------------------
BER OF ELEMENTS          12          15
MENT SIZE              36.00       24.00
K DIMENSION           432.00      360.00


*WARNING**** WHEEL #  2 IS OFF THE DECK TO THE NORTH ****WARNING****


              ******************************
              ******************************
              *                            *
              * RESULTS OF LATEST ANALYSIS *
              *                            *
              ******************************
              ******************************

EEL #    WEIGHT    IN ELEMENT #   AFFECTING NODES    X COORD     Y COORD

          4.00     ABOVE 30          ONLY 48         -108.00      311.77
```

```
3        16.00      ABOVE 23        ONLY 41          -24.00      166.28
4        16.00         70         74 75 90 91         38.35      202.28
5        16.00      RT OF 16        ONLY 33 34        66.00       10.39
6        16.00         63         67 68 83 84        128.35       46.39

ULTANT NODAL LOADS
E #      LOAD (KIPS)

             8.00
             8.00
            16.00
             4.00
             8.49
             2.56
             2.96
             8.09
             3.80
             1.15
             1.33
             3.62

TICS CHECK
AL LOAD ON DECK = 68.00 KIPS
CK WEIGHT = 72.00 KIPS

*NOTE****
CE THE XSHIFT IS ON X INPUT OF  72.00 GIVES X COORD  -24.00

*NOTE****
CE THE YSHIFT IS ON Y INPUT OF 192.00 GIVES Y COORD  166.28
```

```
C******************************************************************
C                                                                 *
C             ********  **    **   ********  **        **         *
C            ********  **   **    ********  **        **          *
C           **        **  **      **         **        **           *
C          ********  *****      ******    **        **            *
C         ********  **  **      ******    **   *    **             *
C              **  **   **    **        **  ***   **              *
C       ********  **    **   ********  ** ** **  **               *
C      ********  **     **  ********    **   **                   *
C                                                                 *
C        **       ********     **     ******     ********  ****** *
C       **       ********    ****    *******    ********  ******* *
C      **       **    **   **  **  **     **    **         **  ** *
C     **       **    **  ********  **     **  ******     *******   *
C    **       **    **  ********  **    **  ******     ******     *
C   **       **    **  **    **  **    **  **         **  **      *
C  *******  ********  **    **  *******   ********   **    **      *
C *******  ********  **    **  ******    ********   **    **      *
C                                                                 *
C******************************************************************
C                                                                 *
C THIS PROGRAM CALCULATES THE SET OF EQUIVALENT NODAL LOADS FOR   *
C ANY TYPE OF TRUCK MOVING ACROSS A SKEWED (PARALLELOGRAM) DECK   *
C OF ANY DIMENSIONS WITH ANY MESH SIZE. THE MESH IS GENERATED     *
C INTERNALLY AND CAN BE OUTPUT OPTIONALLY. THE USER MUST INPUT    *
C THE FOLLOWING:                                                  *
C   (1) 'ALPHA'. GIVE ON THE FIRST DATA CARD THE ALPHA-NUMERIC    *
C       TITLE TO BE PRINTED ON THE OUTPUT LISTING. [77 CHARACTER  *
C       MAXIMUM]                                                  *
C   (2) 'TRTYPE'. ENTER HERE THE INTEGER CORRESPONDING TO THE     *
C       TRUCK TYPE                                                *
C       FOR WHICH THE ANALYSIS IS TO BE PERFORMED. THE OPTIONS    *
C       ARE LISTED BELOW :                                        *
C           (A) 1 IS FDOT TYPE SU-4                               *
C           (B) 9 IS CUSTOM                                       *
C-----------------------------------------------------------------*
C ***NOTE*** IF THE CUSTOM OPTION IS CHOSEN, THEN THE FOLLOWING   *
C            DATA MUST BE ENTERED ON THE NEXT DATA CARDS :        *
C           (A) NUMBER OF AXLES. [INTEGER UP TO 9]                *
C           (B) TRUCK WIDTH (COAXIAL WHEEL SPACING). [REAL]       *
C           (C) SPACING FOR EACH SUCCESSIVE AXLE AS MEASURED      *
C               FROM THE PRECEEDING AXLE (ONE PER DATA CARD).     *
C               NOTE THAT THE # OF AXLE SPACES IS ONE LESS THAN   *
C               THE NUMBER OF AXLES. [REAL]                       *
C           (D) AXLE WEIGHTS (ONE PER DATA CARD IN KIPS). [REAL]  *
C  ALSO NOTE THAT IF THE CUSTOM OPTION IS IN EFFECT THEN THE      *
C  NUMBER OF DATA CARDS WILL VARY.                                *
C-----------------------------------------------------------------*
C   (3) 'PHI'. THE ANGLE OF SKEW (DEGREES). [REAL]                *
C   (4) 'LCN'. THE LOAD CASE NUMBER (ONLY FOR USER'S REFERENCE)  *
C       [INTEGER]                                                 *
C   (5) 'WNUM'. HERE THE USER GIVES AN INTEGER INDICATING WHICH   *
C        ONE OF WHEELS HE WILL LOCATE. THE PROGRAM WILL AUTO-     *
C        MATICALLY LOCATE THE REST (SEE SKETCH FOR RELATIVE       *
C        POSITIONS AND NUMBERING OF THE WHEELS). NOTE THAT THIS   *
C        CARD COMPLETELY ESTABLISHES THE POSITION OF THE TRUCK    *
C        ASSUMING THAT IT IS TRAVELLING PARALLEL TO THE CURB      *
C       (SKEWED EDGE OF THE DECK). [INTEGER]                      *
C   (6) 'XSHIFT'. THIS CARD ALLOWS THE USER THE OPTION OF GIVING  *
C       THE X INPUT AS EITHER SHIFTED OR NORMAL. IF A SHIFTED X   *
C       COORDINATE DESIRED THEN SPECIFY A '1' ON THIS CARD. IF    *
C       NOT, GIVE A '0'. [INTEGER]                                *
C   (7) 'YSHIFT'. THIS CARD ALLOWS THE USER THE OPTION OF INPUT-  *
C       ING EITHER THE Y COORDINATE OR INCLINED SPAN DISTANCE     *
C       ALONG THE SKEWED EDGE. IF SKEWED Y COORDINATE IS DESIRED  *
C       THEN SPECIFY A '1' ON THIS CARD . IF NOT, GIVE A '0'.     *
C       [INTEGER]                                                 *
C   (8) IF CARD #5 IS '0' THEN GIVE ON #7 :                       *
```

```
C             (A) THE X COORDINATE OF THE WHEEL NUMBER GIVEN ON      *
C                 CARD # 4. [REAL]                                   *
C         IF CARD #5 IS '1' THEN GIVE ON #7 :                        *
C            (B) THE X DISTANCE OF THE WHEEL FROM THE LEFT SKEWED    *
C                 EDGE OF THE DECK. [REAL]                           *
C     (9) IF CARD #6 IS '0' THEN GIVE ON #8 :                        *
C             (A) THE Y COORDINATE OF THE WHEEL NUMBER GIVEN ON      *
C                 CARD # 4. [REAL]                                   *
C         IF CARD #6 IS '1' THEN GIVE ON #8 :                        *
C             (B) THE DISTANCE TO THE WHEEL AS MEASURED ALONG THE    *
C                 INCLINED                                           *
C                SPAN EDGE OF THE DECK. [REAL]                       *
C--------------------------------------------------------------------*
C ***NOTE*** THE OPTIONS OF SKEWED COORDINATES ARE INDEPENDENT       *
C FOR THE X AND Y AXES. IT IS RECOMMENDED THAT THE SKEWED OPTION     *
C BE USED WHEN PLACING A WHEEL ON ANY GRID LINE OR MESH NODE,        *
C ALTHOUGH IT IS OFTEN CONVENIENT AT OTHER TIMES AS WELL.            *
C--------------------------------------------------------------------*
C   (10) 'KEY'. IF KEY=0 THE COORDINATE MESH WILL NOT BE PRINTED     *
C        OUT. IF KEY =1 IT WILL. [INTEGER]                           *
C   (11) 'NXSTEP'. THE NUMBER OF ELEMENTS IN THE X DIRECTION.        *
C        [INTEGER]                                                   *
C   (12) 'NYSTEP'. THE NUMBER OF ELEMETS ALONG THE (SKEWED) Y        *
C        DIRECTION. [INTEGER]                                        *
C   (13) 'XINC'. THE X INCREMENT (INCHES). [REAL]                    *
C   (14) 'YSKINC'. THE INCLINED Y INCREMENT (INCHES). [REAL]         *
C--------------------------------------------------------------------*
C***EXAMPLE***                                                       *
C--------------------------------------------------------------------*
C PLACE WHEEL # 3 ON NODE (5,4) OF A 30 DEG SKEWED DECK. THE         *
C DECK MEASURES 540" X 360" (X DIMENSION AND SKEWED SPAN, RESP)      *
C AND THE MESH SIZE IS 54" IN THE X DIRECTION AND 45" IN THE Y       *
C DIRECTION. THUS THERE ARE 10 INCREMENTS ALONG THE X AXIS AND 8     *
C INCREMENTS ALONG THE SKEWED Y AXIS (PLEASE SEE SKETCH). SAY        *
C THE TRUCK TYPE IS FDOT SU-4. WE WOULD INPUT AS FOLLOWS:            *
C                                                                    *
C     CARD      INPUT                         COMMENTS               *
C--------------------------------------------------------------------*
C                                                                    *
C       1    FDOT SU-4 EXAMPLE         OUTPUT LISTING TITLE          *
C       2         1                    TRUCK TYPE IS FDOT SU-4       *
C       3        30.0                  SKEW ANGLE IS 30 DEGREES      *
C       4         1                    LOAD CASE NUMBER (USER'S      *
C                                      OPTION)                       *
C       5         3                    INPUT WHEEL IS #3             *
C       6         1                    THE XSHIFT IS ON              *
C       7         1                    THE YSHIFT IS ON              *
C       8       162.0                  NODE (5,4) IS 162" FROM THE   *
C                                      LEFT EDGE OF THE DECK         *
C       9       180.0                  NODE (5,4) IS 4 SPACES AT     *
C                                      45" EACH (INCLINED DISTANCE)  *
C                                      FROM THE BASE OF THE DECK     *
C      10         0                    KEY=0 MESH WILL NOT BE        *
C                                      PRINTED OUT                   *
C      11        10                    NUMBER OF X STEPS IS 10       *
C      12         8                    NUMBER OF Y STEPS IS 8        *
C      13        54.0                  X INCREMENT IS 54"            *
C      14        45.0                  Y (SKEWED) INCREMENT IS 45"   *
C                                                                    *
C*********************************************************************
      DIMENSION XCOR(30,30), YCOR(30,30), REACT(30,30),
     $ WHEELX(18),WHEELY(18),WT(18),AXLSP(8),AXLWT(9)
      INTEGER XSHIFT,YSHIFT,ERR,WNUM,TRTYPE
      CHARACTER ALPHA*77
      OPEN (UNIT=1,FILE='[.PAUL]LOADER.DAT',STATUS='OLD')
      OPEN (UNIT=6,FILE='[.PAUL]OUTPUT.LIS',STATUS='NEW')
      CALL TITLE1(ALPHA)
      CALL INITL(WJX,WJY,PHI,NXSTEP,NXCROS,XINC,NYSTEP,NYCROS,
     $ YSKINC,LCN,KEY,XSHIFT,YSHIFT,WNUM,AXLSP,NA,NAXLSP,NW,
```

```
     $  WIDTH,TRTYPE,WT,DDX,DDYSK)
        CALL GMESH(PHI,NXSTEP,XINC,NXCROS,XCOR,NYSTEP,YSKINC,
     $  NYCROS,YCOR,KEY,ERR)
        CALL LOCATE(WJX,WJY,W1X,W1Y,PHI,WNUM,ERR,OFFWT,XSHIFT,
     $ YSHIFT,USERX,USERY,AXLSP,NA,NAXLSP,NW,WIDTH,WT,NXCROS,
     $ NYCROS,REACT,WHEELX,WHEELY,DDX,DDYSK)
        CALL TITLE2
        CALL SEARCH(PHI,WT,REACT,XCOR,YCOR,WHEELX,WHEELY,NXSTEP,
     $  NYSTEP,XINC,YSKINC,NXCROS,NYCROS,NW)
        CALL RESULT(NXCROS,NYCROS,REACT,OFFWT,XSHIFT,YSHIFT,
     $  WNUM,USERX,USERY,WJX,WJY)
 910   STOP
        END
        SUBROUTINE INITL(WJX,WJY,PHI,NXSTEP,NXCROS,XINC,NYSTEP,
     $  NYCROS,YSKINC,LCN,KEY,XSHIFT,YSHIFT,WNUM,AXLSP,NA,
     $  NAXLSP,NW,WIDTH,TRTYPE,WT,DDX,DDYSK)
C*****************************************************************
C SUB INITL READS IN THE INPUT DATA AND SETS VARIOUS INITIAL     *
C VALUES BASED ON THIS INFORMATION.                               *
C*****************************************************************
        DIMENSION AXLSP(8),WT(18),AXLWT(9)
        INTEGER XSHIFT,YSHIFT,WNUM,TRTYPE,ERR
        WRITE (6,310)
 310   FORMAT (/,7X,'-----------------------------------------------',
     $  '------------',/,7X,' INPUT CHECK',/,7X,'-----------',
     $  '---------------------------------------')
        READ (1,315) TRTYPE
 315   FORMAT (1I1)
        IF (TRTYPE.NE.1) GO TO 325
        WRITE (6,320)
 320   FORMAT (/,7X,'TRUCK TYPE',18X,'FDOT SU-4')
        CALL TRTYP1(AXLSP,NA,NAXLSP,NW,WIDTH,WT)
        GO TO 360
 325   IF (TRTYPE.NE.9) GO TO 360
        CALL CUSTM1(NA,NAXLSP,NW)
        CALL CUSTM2(AXLSP,NA,NAXLSP,NW,WIDTH,WT,AXLWT)
        WRITE (6,330) NA,WIDTH
 330   FORMAT (/,7X,'TRUCK TYPE',19X,'CUSTOM',//,14X,
     $  'NUMBER OF AXLES',8X,I2,//,14X,'TRUCK AXLE WIDTH',
     $  6X,F6.2)
        DO 340 I=1,NAXLSP
        WRITE (6,335) I,AXLSP(I)
 335   FORMAT (/,14X,'AXLE SPACE # ',I1,8X,F6.2)
 340   CONTINUE
        DO 350 I=1,NA
        WRITE (6,345) I,AXLWT(I)
 345   FORMAT (/,14X,'AXLE WEIGHT # ',I1,7X,F6.2)
 350   CONTINUE
 360   READ (1,362) PHI
 362   FORMAT (1F10.1)
        WRITE (6,364) PHI
 364   FORMAT (/,7X,'ANGLE OF SKEW (DEG)',11X,F4.1)
        READ (1,366) LCN
 366   FORMAT (1I2)
        WRITE (6,368) LCN
 368   FORMAT (/,7X,'LOAD CASE NUMBER',14X,I2)
        READ (1,370) WNUM
 370   FORMAT (1I2)
        WRITE (6,372) WNUM
 372   FORMAT (/,7X,'INPUT WHEEL NUMBER',12X,I2)
        READ (1,374) XSHIFT
 374   FORMAT (1I1)
        READ (1,376) YSHIFT
 376   FORMAT (1I1)
        READ (1,378) WJX
 378   FORMAT (1F7.2)
        READ (1,380) WJY
 380   FORMAT (1F7.2)
        IF (XSHIFT.EQ.0) GO TO 383
```

```
       WRITE (6,382) WJX
 382  FORMAT (/,7X,'X INPUT (SHIFT ON)',10X,F7.2)
       GO TO 386
 383  WRITE (6,384) WJX
 384  FORMAT (/,7X,'X INPUT (SHIFT OFF)',9X,F7.2)
       IF (YSHIFT.EQ.0) GO TO 389
 386  WRITE (6,388) WJY
 388  FORMAT (/,7X,'Y INPUT (SHIFT ON)',10X,F7.2)
       GO TO 392
 389  WRITE (6,390) WJY
 390  FORMAT (/,7X,'Y INPUT (SHIFT OFF)',9X,F7.2)
 392  READ (1,393) KEY
 393  FORMAT (1I1)
       IF (KEY.EQ.0) GO TO 396
       WRITE (6,394)
 394  FORMAT (/,7X,'MESH PRINT REQUEST',13X,'YES')
       GO TO 400
 396  WRITE (6,398)
 398  FORMAT (/,7X,'MESH PRINT REQUEST',12X,'NO')
 400  WRITE (6,405)
 405  FORMAT (///,7X,'-----------------------------------',
     $ '----------------------',/,7X,'MESH DATA',16X,'X-AXIS',
     $ 6X,'Y-AXIS (SKEWED)',/,7X,'-----------------------------',
     $ '------------------------------')
       READ (1,410) NXSTEP
 410  FORMAT (1I2)
       READ (1,412) NYSTEP
 412  FORMAT (1I2)
       WRITE (6,414) NXSTEP,NYSTEP
 414  FORMAT (/,7X,'NUMBER OF ELEMENTS',9X,I2,10X,I2)
       READ (1,420) XINC
 420  FORMAT (1F6.2)
       READ (1,430) YSKINC
 430  FORMAT (1F6.2)
       WRITE (6,432) XINC,YSKINC
 432  FORMAT (/,7X,'ELEMENT SIZE',14X,F6.2,6X,F6.2)
       DDX=NXSTEP*XINC
       DDYSK=NYSTEP*YSKINC
       WRITE (6,434) DDX,DDYSK
 434  FORMAT (/,7X,'DECK DIMENSION',11X,F7.2,5X,F7.2)
       NXCROS=NXSTEP+1
       NYCROS=NYSTEP+1
 530  RETURN
       END
       SUBROUTINE GMESH(PHI,NXSTEP,XINC,NXCROS,XCOR,NYSTEP,
     $ YSKINC,NYCROS,YCOR,KEY,ERR)
C*******************************************************************
C SUB GMESH GENERATES THE SKEWED MESH AND ALLOWS FOR OPTIONAL      *
C PRINTOUT FOR KEY=1.                                              *
C*******************************************************************
       DIMENSION XCOR(NYCROS,NXCROS),YCOR(NYCROS,NXCROS)
       INTEGER ERR
       PHI=3.14159265359*PHI/180.
       X=0.0
       Y=0.0
       A=0.0
       XSTEP=0.0
       NCOUNT=0
       ERR=0
       DO 590 J=1,NXCROS
       DO 580 I=1,NYCROS
       NCOUNT=NCOUNT+1
       YCOR(I,J)=Y
       XCOR(I,J)=X
       IF (KEY.EQ.0) GO TO 570
       WRITE(6,560) NCOUNT,I,J,X,Y
 560  FORMAT (/,5X,'NODE # ',I3,5X,'(I,J)=(',I2,',',I2,')',5X,
     $ 'X=',F7.2,3X,'Y=',F7.2)
 570  A=A+YSKINC
```

```
        X1=A*SIN(PHI)
        Y1=A*COS(PHI)
        X=XSTEP-X1
        Y=Y1
 580   CONTINUE
        A=0.0
        Y=0.0
        XSTEP=XSTEP+XINC
        X=XSTEP
 590   CONTINUE
        RETURN
        END
 940   SUBROUTINE LOCATE(WJX,WJY,W1X,W1Y,PHI,WNUM,ERR,OFFWT,
     $  XSHIFT,YSHIFT,USERX,USERY,AXLSP,NA,NAXLSP,NW,WIDTH,WT,
     $  NXCROS,NYCROS,REACT,WHEELX,WHEELY,DDX,DDYSK)
C*******************************************************************
C SUB LOCATE USES THE INPUT WHEEL COORDINATES OF WJX AND WJY TO     *
C FIND THE COORDINATES OF THE LEFT FRONT (i.e., DRIVER'S) WHEEL.    *
C THEN IT WILL LOCATE THE COORDINATES OF THE REST BASED ON THIS     *
C POSITION. IT ALSO CHECKS TO BE CERTAIN THAT EACH WHEEL FALLS      *
C ON THE DECK ITSELF AND PRINTS A WARNING LIST FOR THOSE WHEELS     *
C THAT ARE NOT WITHIN THE DECK BOUNDARIES. THE TOTAL WEIGHT OF      *
C THE WHEELS THAT ARE OFF THE DECK WILL BE CONSIDERED IN THE        *
C STATICS CHECK AT THE END OF THE PROGRAM.                          *
C*******************************************************************
        DIMENSION WT(NW),AXLSP(NAXLSP),WHEELX(NW),WHEELY(NW),
     $ REACT(NYCROS,NXCROS)
        INTEGER WNUM,ERR,XSHIFT,YSHIFT
        IF (WNUM.LE.NW) GO TO 602
        WRITE (1,600)
 600   FORMAT (//,7X,'*** ERROR *** ILLEGAL WHEEL NUMBER INPUT')
        ERR=1
        GO TO 1090
 602   USERX=WJX
        USERY=WJY
        IF (YSHIFT.EQ.0) GO TO 607
        WJY=WJY*COS(PHI)
 607   IF (XSHIFT.EQ.0) GO TO 910
        WJX=WJX-(WJY*SIN(PHI)/SIN(1.570796327-PHI))
 910   Z1=WIDTH*COS(PHI)
        Z2=WIDTH*SIN(PHI)
        IF (WNUM.NE.1) GO TO 942
        W1X=WJX
        W1Y=WJY
        GO TO 980
 942   IF (WNUM.NE.2) GO TO 944
        W1X=WJX-Z1
        W1Y=WJY-Z2
        GO TO 980
 944   A=AXLSP(1)
        IF (WNUM.NE.3) GO TO 946
        W1X=WJX-(A)*SIN(PHI)
        W1Y=WJY+(A)*COS(PHI)
        GO TO 980
 946   IF (WNUM.NE.4) GO TO 948
        W1X=WJX-((A)*SIN(PHI)+Z1)
        W1Y=WJY+((A)*COS(PHI)-Z2)
        GO TO 980
 948   B=AXLSP(2)
        IF (WNUM.NE.5) GO TO 950
        W1X=WJX-(A+B)*SIN(PHI)
        W1Y=WJY+(A+B)*COS(PHI)
        GO TO 980
 950   IF (WNUM.NE.6) GO TO 952
        W1X=WJX-((A+B)*SIN(PHI)+Z1)
        W1Y=WJY+((A+B)*COS(PHI)-Z2)
        GO TO 980
 952    C=AXLSP(3)
        IF (WNUM.NE.7) GO TO 954
```

```
       W1X=WJX-(A+B+C)*SIN(PHI)
       W1Y=WJY+(A+B+C)*COS(PHI)
       GO TO 980
954   IF (WNUM.NE.8) GO TO 956
       W1X=WJX-((A+B+C)*SIN(PHI)+Z1)
       W1Y=WJY+((A+B+C)*COS(PHI)-Z2)
       GO TO 980
956    D=AXLSP(4)
       IF (WNUM.NE.9) GO TO 958
       W1X=WJX-(A+B+C+D)*SIN(PHI)
       W1Y=WJY+(A+B+C+D)*COS(PHI)
       GO TO 980
958   IF (WNUM.NE.10) GO TO 960
       W1X=WJX-((A+B+C+D)*SIN(PHI)+Z1)
       W1Y=WJY+((A+B+C+D)*COS(PHI)-Z2)
       GO TO 980
960    E=AXLSP(5)
       IF (WNUM.NE.11) GO TO 962
       W1X=WJX-(A+B+C+D+E)*SIN(PHI)
       W1Y=WJY+(A+B+C+D+E)*COS(PHI)
       GO TO 980
962   IF (WNUM.NE.12) GO TO 964
       W1X=WJX-((A+B+C+D+E)*SIN(PHI)+Z1)
       W1Y=WJY+((A+B+C+D+E)*COS(PHI)-Z2)
       GO TO 980
964    F=AXLSP(6)
       IF (WNUM.NE.13) GO TO 966
       W1X=WJX-(A+B+C+D+E+F)*SIN(PHI)
       W1Y=WJY+(A+B+C+D+E+F)*COS(PHI)
       GO TO 980
966   IF (WNUM.NE.14) GO TO 968
       W1X=WJX-((A+B+C+D+E+F)*SIN(PHI)+Z1)
       W1Y=WJY+((A+B+C+D+E+F)*COS(PHI)-Z2)
       GO TO 980
968    G=AXLSP(7)
       IF (WNUM.NE.15) GO TO 970
       W1X=WJX-(A+B+C+D+E+F+G)*SIN(PHI)
       W1Y=WJY+(A+B+C+D+E+F+G)*COS(PHI)
       GO TO 980
970   IF (WNUM.NE.16) GO TO 972
       W1X=WJX-((A+B+C+D+E+F+G)*SIN(PHI)+Z1)
       W1Y=WJY+((A+B+C+D+E+F+G)*COS(PHI)-Z2)
       GO TO 980
972    H=AXLSP(8)
       IF (WNUM.NE.17) GO TO 974
       W1X=WJX-(A+B+C+D+E+F+G+H)*SIN(PHI)
       W1Y=WJY+(A+B+C+D+E+F+G+H)*COS(PHI)
       GO TO 980
974   IF (WNUM.NE.18) GO TO 976
       W1X=WJX-((A+B+C+D+E+F+G+H)*SIN(PHI)+Z1)
       W1Y=WJY+((A+B+C+D+E+F+G+H)*COS(PHI)-Z2)
       GO TO 980
976   WRITE (6,978)
978    FORMAT (//,7X,'****ERROR**** ILLEGAL WHEEL NUMBER INPUT',
     $ ' ON DATA CARD # 10')
       ERR=1
       GO TO 1090
980   I=0
       WHEELX(1)=W1X
       WHEELX(2)=W1X+Z1
       WHEELY(1)=W1Y
       WHEELY(2)=W1Y+Z2
       I=I+2
       IF (I.EQ.NW) GO TO 1010
       A=AXLSP(1)
       WHEELX(3)=W1X+(A)*SIN(PHI)
       WHEELX(4)=WHEELX(3)+Z1
       WHEELY(3)=W1Y-A*COS(PHI)
       WHEELY(4)=WHEELY(3)+Z2
```

```
       I=I+2
       IF (I.EQ.NW) GO TO 1010
       B=AXLSP(2)
       WHEELX(5)=W1X+(A+B)*SIN(PHI)
       WHEELX(6)=WHEELX(5)+Z1
       WHEELY(5)=W1Y-(A+B)*COS(PHI)
       WHEELY(6)=WHEELY(5)+Z2
       I=I+2
       IF (I.EQ.NW) GO TO 1010
       C=AXLSP(3)
       WHEELX(7)=W1X+(A+B+C)*SIN(PHI)
       WHEELX(8)=WHEELX(7)+Z1
       WHEELY(7)=W1Y-(A+B+C)*COS(PHI)
       WHEELY(8)=WHEELY(7)+Z2
       I=I+2
       IF (I.EQ.NW) GO TO 1010
       D=AXLSP(4)
       WHEELX(9)=W1X+(A+B+C+D)*SIN(PHI)
       WHEELX(10)=WHEELX(9)+Z1
       WHEELY(9)=W1Y-(A+B+C+D)*COS(PHI)
       WHEELY(10)=WHEELY(9)+Z2
       I=I+2
       IF (I.EQ.NW) GO TO 1010
       E=AXLSP(5)
       WHEELX(11)=W1X+(A+B+C+D+E)*SIN(PHI)
       WHEELX(12)=WHEELX(11)+Z1
       WHEELY(11)=W1Y-(A+B+C+D+E)*COS(PHI)
       WHEELY(12)=WHEELY(11)+Z2
       I=I+2
       IF (I.EQ.NW) GO TO 1010
       F=AXLSP(6)
       WHEELX(13)=W1X+(A+B+C+D+E+F)*SIN(PHI)
       WHEELX(14)=WHEELX(13)+Z1
       WHEELY(13)=W1Y-(A+B+C+D+E+F)*COS(PHI)
       WHEELY(14)=WHEELY(13)+Z2
       I=I+2
       IF (I.EQ.NW) GO TO 1010
       G=AXLSP(7)
       WHEELX(15)=W1X+(A+B+C+D+E+F+G)*SIN(PHI)
       WHEELX(16)=WHEELX(15)+Z1
       WHEELY(15)=W1Y-(A+B+C+D+E+F+G)*COS(PHI)
       WHEELY(16)=WHEELY(15)+Z2
       I=I+2
       IF (I.EQ.NW) GO TO 1010
       H=AXLSP(8)
       WHEELX(17)=W1X+(A+B+C+D+E+F+G+H)*SIN(PHI)
       WHEELX(18)=WHEELX(17)+Z1
       WHEELY(17)=W1Y-(A+B+C+D+E+F+G+H)*COS(PHI)
       WHEELY(18)=WHEELY(17)+Z2
       I=I+2
       IF (I.EQ.NW) GO TO 1010
       WRITE (6,990)
990    FORMAT (//,7X,'ILLEGAL NUMBER OF WHEELS INPUT')
       GO TO 1090
1010  OFFWT=0.0
       DO 1080 I=1,8
       A=WHEELY(I)
       IF (A.GE.0.0) GO TO 1015
       OFFWT=OFFWT+WT(I)
       WT(I)=0.0
       WRITE (6,1013) I
1013  FORMAT (///,7X,'***WARNING**** WHEEL # ',I2,
    $ ' IS OFF THE DECK TO THE SOUTH')
       GO TO 1080
1015  PSD=DDYSK*COS(PHI)
       IF (A.LE.PSD) GO TO 1025
       OFFWT=OFFWT+WT(I)
       WT(I)=0.0
       WRITE (6,1020) I
```

```
 1020  FORMAT (///,7X,'****WARNING**** WHEEL # ',I2,
     $  ' IS OFF THE DECK TO THE NORTH')
        GO TO 1080
 1025  OFFSET=A*SIN(PHI)/SIN(1.570796327-PHI)
        B=WHEELX(I)
        B1=DDX-OFFSET
        IF (B.LE.B1) GO TO 1035
        OFFWT=OFFWT+WT(I)
        WT(I)=0.0
        WRITE (6,1030) I
 1030  FORMAT (///,7X,'****WARNING**** WHEEL # ',I2,
     $  'IS OFF THE DECK TO THE EAST')
        GO TO 1080
 1035  B1=0.0-OFFSET
        IF (B.GE.B1) GO TO 1080
        OFFWT=OFFWT+WT(I)
        WT(I)=0.0
        WRITE (6,1040) I
 1040  FORMAT (///,7X,'****WARNING**** WHEEL # ',I2,
     $  ' IS OFF THE DECK TO THE WEST')
 1080  CONTINUE
 640   DO 650 I=1,NYCROS
        DO 650 J=1,NXCROS
        REACT(I,J)=0.0
 650   CONTINUE
 1090  RETURN
        END
        SUBROUTINE SEARCH(PHI,WT,REACT,XCOR,YCOR,WHEELX,
     $  WHEELY,NXSTEP,NYSTEP,XINC,YSKINC,NXCROS,NYCROS,NW)
C*****************************************************************
C SUB SEARCH IS USED TO FIND THE LOCATION OF EACH WHEEL WITH     *
C RESPECT TO ITS SURROUNDING NODES. DO THIS BY FIRST SEARCHING   *
C VERTICALLY TO GET DISTANCES D1 & D2 WHICH ARE THE COORDINATES  *
C OF THE NODES IMMEDIATELY ABOVE & BELOW THE WHEEL, RESP. THEN   *
C SEARCH HORIZONTALLY ALONG THE Y COORDINATE OF D2 TO GET THE    *
C DISTANCES D3 AND D4 WHICH ARE THE PROPER X COORDINATES OF THE  *
C NODES ALONG THIS LOWER 'TRACK'. THEN USE A SIMILAR PROCEDURE   *
C FOR D5 AND D6 ALONG THE UPPER 'TRACK'.                         *
C*****************************************************************
        DIMENSION WT(NW),REACT(NYCROS,NXCROS),
     $  XCOR(NYCROS,NXCROS),YCOR(NYCROS,NXCROS),WHEELX(NW),
     $  WHEELY(NW)
        DO 850 K=1,NW
        WTCHK=WT(K)
        IF (WTCHK.EQ.0.0) GO TO 850
        I=1
        LCOUNT=0
 705   C=YCOR(I,1)
        D=WHEELY(K)
        CALL RNDOFF(C,D)
        IF (C.EQ.D) GO TO 710
        IF (C.GT.D) GO TO 720
        I=I+1
        LCOUNT=LCOUNT+1
        GO TO 705
 710   I1=I
        NE=I1
        D1=YCOR(I1,1)
        GO TO 721
 720   I1=I
        I2=I1-1
        NNE=I1
        NSE=I2
        D1=YCOR(I1,1)
        D2=YCOR(I2,1)
        GO TO 729
 721   N=1
        LCOUNT=LCOUNT-NYSTEP
        F=WHEELX(K)
```

```
722   G=XCOR(I1,N)
       CHECK3=ABS(WHEELX(K)-(N-1)*XINC)
       CHECK4=ABS(WHEELY(K)*SIN(PHI)/SIN(1.570796327-PHI))
       CALL RNDOFF(CHECK3,CHECK4)
       CALL RNDOFF(G,F)
       IF (CHECK3.EQ.CHECK4) GO TO 723
       IF (G.GT.F) GO TO 725
       N=N+1
       LCOUNT=LCOUNT+NYSTEP
       NE=NE+NYCROS
       GO TO 722
723   I5=N
       D5=XCOR(I1,I5)
       W=WT(K)
       A=WHEELX(K)
       B=WHEELY(K)
       WRITE (6,724) K,W,LCOUNT,NE,A,B
724   FORMAT (/,9X,I1,6X,F5.2,4X,'ABOVE ',I2,8X,'ONLY ',
    $  I2,7X,F7.2,2X,F7.2)
       RS=WT(K)
       REACT(I1,I5)=REACT(I1,I5)+RS
       GO TO 850
725   I5=N
       I6=N-1
       D5=XCOR(I1,I5)
       D6=XCOR(I1,I6)
       NW=NE-NYCROS
       W=WT(K)
       A=WHEELX(K)
       B=WHEELY(K)
       WRITE (6,726) K,W,LCOUNT,NW,NE,A,B
726   FORMAT (/,9X,I1,6X,F5.2,4X,'ABOVE ',I2,8X,'ONLY ',
    $  I2,1X,I2,4X,F7.2,2X,F7.2)
       RL=(D5-A)*WT(K)/(D5-D6)
       RR=WT(K)-RL
       REACT(I1,I5)=REACT(I1,I5)+RR
       REACT(I1,I6)=REACT(I1,I6)+RL
       GO TO 850
729   L=1
       LCOUNT=LCOUNT-NYSTEP
730   E=XCOR(I2,L)
       F=WHEELX(K)
       CHECK4=ABS(WHEELY(K)*SIN(PHI)/SIN(1.570796327-PHI))
       CHECK5=ABS(WHEELX(K)-(L-1)*XINC)
       CALL RNDOFF(CHECK5,CHECK4)
       CALL RNDOFF(E,F)
       IF (CHECK5.EQ.CHECK4) GO TO 731
       IF (E.GT.F) GO TO 740
       L=L+1
       LCOUNT=LCOUNT+NYSTEP
       NSE=NSE+NYCROS
       GO TO 730
731   I3=L
       I5=I3
       D3=XCOR(I2,I3)
       D5=XCOR(I1,I3)
       NB=NSE
       NA=NB+1
       W=WT(K)
       A=WHEELX(K)
       B=WHEELY(K)
       WRITE (6,732) K,W,LCOUNT,NB,NA,A,B
732   FORMAT (/,9X,I1,6X,F5.2,4X,'RT OF ',I2,8X,'ONLY ',
    $  I2,1X,I2,4X,F7.2,2X,F7.2)
       RA=WT(K)*(B-D2)/(D1-D2)
       RB=WT(K)-RA
       REACT(I2,I3)=REACT(I2,I3)+RB
       REACT(I1,I5)=REACT(I1,I5)+RA
       GO TO 850
```

```
 740    XOFF1=(D-D2)*SIN(PHI)/SIN(1.570796327-PHI)
         CHECK1=XCOR(I2,L)
         WXOFF1=CHECK1-F
         CALL RNDOFF(WXOFF1,XOFF1)
         IF (WXOFF1.GT.XOFF1) GO TO 750
         I3=L+1
         I4=L
         LCOUNT=LCOUNT+NYSTEP
         NSE=NSE+NYCROS
         GO TO 760
 750    I3=L
         I4=L-1
 760    D3=XCOR(I2,I3)
         D4=XCOR(I2,I4)
         NSW=NSE-NYCROS
         N=1
 770    G=XCOR(I1,N)
         CALL RNDOFF(G,F)
         IF (G.GT.F) GO TO 780
         N=N+1
         NNE=NNE+NYCROS
         GO TO 770
 780    XOFF2=(D1-D)*SIN(PHI)/SIN(1.570796327-PHI)
         CHECK2=XCOR(I1,N)
         WXOFF2=F-(CHECK2-XINC)
         CALL RNDOFF(WXOFF2,XOFF2)
         IF (WXOFF2.GT.XOFF2) GO TO 790
         I5=N-1
         I6=N-2
         NNE=NNE-NYCROS
         LCOUNT=LCOUNT-NYSTEP
         GO TO 795
 790    I5=N
         I6=N-1
 795    D5=XCOR(I1,I5)
         D6=XCOR(I1,I6)
         NNW=NNE-NYCROS
         W=WT(K)
         A=WHEELX(K)
         B=WHEELY(K)
         WRITE (6,797) K,W,LCOUNT,NSW,NNW,NSE,NNE,A,B
 797    FORMAT (/,9X,I1,6X,F5.2,7X,I2,10X,I2,1X,I2,1X,I2,
     $   1X,I2,4X,F7.2,2X,F7.2)
C*********************************************************************
C COMPUTE NODAL POINT REACTIONS BY PUTTING AN IMAGINARY STRINGER *
C HORIZONTALLY ACROSS THE ELEMENT AND FINDING THE EQUIVALENT     *
C STATIC LOADS ON THE SKEWED EDGES.  THEN PUT TWO IMAGINARY      *
C STRINGERS ALONG THE SKEWED EDGES AND SOLVE FOR THE NODAL POINT *
C LOADS.  AS THE REACTIONS FROM EACH WHEEL ARE FOUND, KEEP A     *
C RUNNING TOTAL OF EACH WHEEL'S CONTRIBUTION IN A STORAGE MATRIX *
C REACT(I,J).                                                    *
C*********************************************************************
         D7=WHEELX(K)-D4
         D8=(WHEELY(K)-D2)*SIN(PHI)/SIN(1.570796327-PHI)
         RL=WT(K)*((D3-D4)-(D7+D8))/(D3-D4)
         RR=WT(K)-RL
         RNNW=RL*(WHEELY(K)-D2)/(D1-D2)
         RNSW=RL*(D1-WHEELY(K))/(D1-D2)
         RNNE=RR*(WHEELY(K)-D2)/(D1-D2)
         RNSE=RR*(D1-WHEELY(K))/(D1-D2)
 800    REACT(I1,I6)=REACT(I1,I6)+RNNW
         REACT(I2,I4)=REACT(I2,I4)+RNSW
         REACT(I1,I5)=REACT(I1,I5)+RNNE
         REACT(I2,I3)=REACT(I2,I3)+RNSE
 850    CONTINUE
         RETURN
         END
 915    SUBROUTINE RNDOFF(X,Y)
C********************************************************************
```

```
C SUBROUTINE RNDOFF ROUNDS OFF THE VALUES ASSIGNED TO X AND Y     *
C TO THREE DECIMAL PLACES.                                        *
******************************************************************
        X=1000.0*X
        Y=1000.0*Y
        X=ANINT(X)/1000.0
        Y=ANINT(Y)/1000.0
        RETURN
        END
        SUBROUTINE RESULT(NXCROS,NYCROS,REACT,OFFWT,XSHIFT,
     $  YSHIFT,WNUM,USERX,USERY,WJX,WJY)
C*****************************************************************
C SUB RESULT OUTPUTS THE RESULTANT (NON-ZERO) NODAL LOADS AND     *
C CHECKS BY STATICS TO ASSURE THAT THE SUM OF THE WEIGHTS OF      *
C THE 'OFF-WHEELS' ADDS UP TO THE TRUCK WEIGHT.                   *
C*****************************************************************
        DIMENSION REACT(NYCROS,NXCROS)
        INTEGER XSHIFT,YSHIFT,WNUM
        TOTAL=0.0
        NCOUNT=1
        WRITE (6,855)
 855   FORMAT ('1',////,7X,'RESULTANT NODAL LOADS',//,7X,'NODE #',
     $ 5X,'LOAD (KIPS)',/)
        DO 880 J=1,NXCROS
        DO 870 I=1,NYCROS
        R=REACT(I,J)
        IF (R.EQ.0.0) GO TO 860
        TOTAL=TOTAL+R
        WRITE (6,857) NCOUNT,R
 857   FORMAT (/,8X,I2,9X,F7.2)
 860   NCOUNT=NCOUNT+1
 870   CONTINUE
 880   CONTINUE
        TRKWT=TOTAL+OFFWT
        WRITE (6,890) TOTAL,TRKWT
 890   FORMAT (////,7X,'STATICS CHECK',//,7X,
     $  'TOTAL LOAD ON DECK = ',F5.2,' KIPS',//,7X,
     $  'TRUCK WEIGHT = ',F5.2,' KIPS')
        IF (XSHIFT.EQ.0) GO TO 900
        WRITE (6,895) USERX,WJX
 895   FORMAT (//,7X,'****NOTE****',//,7X,'SINCE THE XSHIFT',
     $  ' IS ON X INPUT OF',F7.2,' GIVES X COORD ',F7.2)
 900   IF (YSHIFT.EQ.0) GO TO 910
        WRITE (6,905) USERY,WJY
 905   FORMAT (//,7X,'****NOTE****',//,7X,'SINCE THE YSHIFT',
     $  ' IS ON Y INPUT OF',F7.2,' GIVES Y COORD ',F7.2)
 910   RETURN
        END
        SUBROUTINE TRTYP1(AXLSP,NA,NAXLSP,NW,WIDTH,WT)
C*****************************************************************
C SUB TRTYP1 HOLDS THE REQUIRED INPUT DATA FOR THE FDOT SU-4      *
C TYPE TRUCK                                                      *
C*****************************************************************
        DIMENSION AXLSP(3),WT(8)
        NA=4
        NAXLSP=3
        NW=8
        WIDTH=76.0
        AXLSP(1)=110.0
        AXLSP(2)=50.0
        AXLSP(3)=50.0
        WT(1)=6.95
        WT(2)=6.95
        DO 950 I=3,8
        WT(I)=9.35
 950   CONTINUE
        RETURN
        END
        SUBROUTINE CUSTM1(NA,NAXLSP,NW)
```

```
C*****************************************************************
C SUB CUSTM1 READS IN THE NUMBER OF AXLES AND FINDS THE NUMBER   *
C OF AXLE SPACES AND THE NUMBER OF WHEELS. THE INFORMATION IS    *
C REQUIRED FOR THE VARIABLE DIMENSIONS IN SUB CUSTM2.            *
C*****************************************************************
        READ (1,705) NA
 705   FORMAT (1I1)
        NAXLSP=NA-1
        NW=2*NA
        RETURN
        END
        SUBROUTINE CUSTM2(AXLSP,NA,NAXLSP,NW,WIDTH,WT,AXLWT)
C*****************************************************************
C SUB CUSTM2 READS IN THE REST OF THE REQUIRED DATA FOR ANY      *
C TYPE OF TRUCK                                                  *
C*****************************************************************
        DIMENSION AXLSP(NAXLSP),WT(NW),AXLWT(NA)
        READ (1,740) WIDTH
 740   FORMAT (1F6.2)
        DO 770 I=1,NAXLSP
        READ (1,750) AXLSP(I)
 750   FORMAT (1F6.2)
 770   CONTINUE
        DO 780 I=1,NA
        READ (1,775) AXLWT(I)
 775   FORMAT (1F6.2)
 780   CONTINUE
        DO 790 K=1,NA
        I=2*K-1
        J=2*K
        WT(I)=AXLWT(K)/2
        WT(J)=WT(I)
 790   CONTINUE
        RETURN
        END
        SUBROUTINE TITLE1(ALPHA)
C*****************************************************************
C SUB TITLE1 READS IN AND ECHO PRINTS THE TITLE OF THE OUTPUT    *
C LISTING                                                        *
C*****************************************************************
        CHARACTER ALPHA*77
        READ (1,200) ALPHA
 200   FORMAT (A77)
        WRITE (6,210) ALPHA
 210   FORMAT (///,7X,A77)
        RETURN
        END
        SUBROUTINE TITLE2
        WRITE (6,700)
 700   FORMAT (///,20X,'******************************',/,20X,
     $ '******************************',/,20X,'*',28X,'*',/,20X,
     $ '* RESULTS OF LATEST ANALYSIS *',/,20X,'*',28X,'*',/,20X,
     $ '******************************',/,20X,
     $ '******************************',///,7X,'WHEEL #',
     $ 2X,'WEIGHT',2X,'IN ELEMENT #',2X,'AFFECTING NODES',2X,
     $ 'X COORD',2X,'Y COORD',/)
        RETURN
        END
```

```
C*****************************************************************
C                           CREATE.FOR                           *
C*****************************************************************
      CHARACTER BUFFER*9,BETA*79,ALPHA*44,GAMMA*15
      OPEN (UNIT=1,FILE='[.PAUL]OUTPUT.LIS',STATUS='OLD')
      OPEN (UNIT=2,FILE='[.PAUL]PS20100.DAT',STATUS='OLD')
      OPEN (UNIT=3,FILE='[.PAUL]PS20100.DAT',STATUS='NEW')
      DO 10 I=1,1000
      READ (1,5) BUFFER
 5    FORMAT (3X,A9)
      IF (BUFFER.EQ.'RESULTANT') GO TO 15
 10   CONTINUE
 15   READ (1,20) NJ,FJ
 20   FORMAT (////,3X,I3,11X,F5.2)
      FJ=-FJ
      READ (2,'(A79)') BETA
      WRITE (3,'(A79)') BETA
      READ (2,'(A44,1F5.1,A15)') ALPHA,POSIT,GAMMA
      POSIT=POSIT+12.0
      WRITE (3,'(A44,F5.1,A15)') ALPHA,POSIT,GAMMA
      DO 30 I=1,23
      READ (2,'(A79)') BETA
      WRITE (3,'(A79)') BETA
 30   CONTINUE
      WRITE (3,40) NJ,FJ
      DO 50 I=1,25
      READ (1,35) NJ,FJ
 35   FORMAT (/,3X,I3,11X,F5.2)
      FJ=-FJ
      IF (NJ.EQ.0) GO TO 70
      WRITE (3,40) NJ,FJ
 40   FORMAT (I3,1X,'FORCE Z ',F5.2)
 50   CONTINUE
 70   WRITE (3,80)
 80   FORMAT ('STIFFNESS ANALYSIS',/,
     $ 'CALCULATE AVERAGE PRINCIPAL BENDING RESULTANTS',/,
     $ 'FINISH')
      STOP
      END
```

GTSTR.COM

```
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS201001.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS201002.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS201003.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS201004.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS201005.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS201006.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS201007.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS201008.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS201009.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS2010010.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS2010011.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS2010012.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS2010013.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS2010014.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS2010015.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS2010016.LIS/N
$ @[.PAUL]RUN
$ GTSTRUDL [.PAUL]PS20100.DAT; PR=[.PAUL]PS2010017.LIS/N
```

RUN.COM

```
$ FOR [.PAUL]INC
$ LINK INC
$ RUN INC
$ FOR [.PAUL]LOADER
$ LINK LOADER
$ RUN LOADER
$ FOR [.PAUL]CREATE
$ LINK CREATE
$ RUN CREATE
$ DEL INC.*;*
$ DEL CREATE.*;*
$ DEL LOADER.*;*
$ DEL [.PAUL]PS20100.SAV;*
```

APPENDIX B

SAMPLE GTSTRUDL OUTPUT

```
                                                                          GTICES 1.2   13-JUL-1984 11:58:55.26   PAGE       1

X 1.2 ** Proprietary to the Georgia Tech Research Institute.
E=GTI_STRUDL:GTIST8302.CDB/IF_2=GTI_STRUDL:GTIST8302.DS/NODUMP/POOL_INCR=16384/IF_1=USERDAT.DS/IF_7=PLOTFIL.DS
DIRECT ‘C.PAUL]PS20100.SAV’
I-NOMSG, Message number 08058053
SKEW=20.0, LSR=1.00, POSITION=W5 AT  26.0 CTR’




*************************************************************
                                                            *
***                            G T S T R U D L              *
****                       OCTOBER   1983 - 83.02-759       *
  **                                                        *
             *****  ******  *****   **  **  *****   **      *
**********  ******  ******  ******  **  **  ******  **      *
**********  **        **    **  **  **  **  **  **  **      *
  ****      *****     **    ******  **  **  **  **  **      *
******       *****    **    *****   **  **  **  **  **      *
*** **          **    **    ** **   **  **  **  **  **      *
    **      ******    **    **  **  ******  ******  ******  *
    **      *****     **    **  **   ****   *****   ******  *
    **                                                      *
    **                 OWNED BY AND PROPRIETARY TO THE      *
    **                 GEORGIA TECH RESEARCH INSTITUTE      *
                                                            *
*************************************************************



IVE UNITS -  LENGTH   WEIGHT   ANGLE    TEMPERATURE  TIME
UNED TO BE      INCH    POUND   RADIAN    FAHRENHEIT  SECOND

TE BENDING
MENTARY TO FDOT HIGHWAY BRIDGE ANALYSIS PROJECT.
METER STUDY IS USED TO INVESTIGATE THE EFFECT OF
NGLE ON BRIDGE DECKS OF VARIOUS ASPECT RATIOS.
PS, IN, DEG
NERATE OFF
ORDINATES
 9 JOINTS ID 1,1 X 0.0 -16.41696683 Y 0.0 45.1052458
 TIMES ID 9 X 48.0
UPPORT 1 TO 73 BY 9, 9 TO 81 BY 9
INCIDENCES
 8 ELEMENTS ID 1,1 FROM 1,1 TO 10,1 TO 11,1 TO 2,1
 TIMES ID 8 FROM 9 TO 9 TO 9 TO 9
LEASES
BY 9 MOMENT X, MOMENT Y
BY 9 MOMENT X, MOMENT Y
PROPERTIES
TYPE ‘BPP’ THICKNESS 18.0
S
 ALL
0.15 ALL
1 ‘FDOT SU-4 ROLLS ACROSS DECK CENTER’
ADS
 Z -0.33
```

```
Z -7.55
Z -7.88
Z -7.55
Z -0.33
Z -3.90
Z -1.95
Z -0.06
Z -2.10
Z -2.88
Z -2.82
Z -0.97
Z -0.83
Z -1.36
Z -3.67
Z -7.55
Z -7.55
Z -4.87
Z -0.53
Z -5.33
S ANALYSIS


H INFORMATION BEFORE RENUMBERING.


UM BANDWIDTH IS   10 AND OCCURS AT JOINT 11
GE BANDWIDTH IS                        8.889
ARD DEVIATION OF THE BANDWIDTH IS      2.846
                                    ----------
                                      11.735
                                    ==========

H REDUCTION HAS FAILED TO PRODUCE A BETTER NUMBERING.
 NUMBERING WILL BE USED.

 CONSISTENCY CHECKS FOR   64 MEMBERS    6.38 SECONDS
 BANDWIDTH REDUCTION                    5.95 SECONDS
ENERATE   64 ELEMENT STIF. MATRICES    12.54 SECONDS
SSEMBLE THE STIFFNESS MATRIX           12.51 SECONDS
ROCESS   81 JOINTS                      5.66 SECONDS
OLVE WITH   21 PARTITIONS              21.24 SECONDS
ROCESS    81 JOINT DISPLACEMENTS        1.58 SECONDS
ROCESS   64 ELEMENT REACTIONS           9.11 SECONDS
ROCESS   64 ELEMENT STRESSES            9.14 SECONDS
 STATICS CHECK                          2.46 SECONDS
E AVERAGE PRINCIPAL BENDING RESULTANTS
CE SPECIFICATION MISSING - MIDDLE SURFACE ASSUMED
NT LIST MISSING - ALL ASSUMED
```

```
                                                                                  GTICES 1.2   13-JUL-1984 12:01:26.99   PAGE      3



**********************
LTS OF LATEST ANALYSES*
**********************


LEM - SKEW=20.  TITLE - NONE GIVEN


VE UNITS  INCH KIP  DEG  DEGF SEC



==============================================================================================================================
G - 1            FDOT SU-4 ROLLS ACROSS DECK CENTER
==============================================================================================================================


IPAL BENDING RESULTANTS BASED ON AVERAGE BENDING RESULTANTS

   NUMBER OF ELEMENTS          M1               M2              MXYMAX            THETA
   USED IN AVERAGING

              1           0.334013E+00    -0.793778E+00    0.563896E+00     0.197071E+02

              2           0.240002E+00    -0.636123E+01    0.330062E+01     0.730500E+01

              2           0.362035E+00    -0.851363E+01    0.443783E+01     0.713004E+01

              2           0.439981E+00    -0.870787E+01    0.457393E+01     0.620307E+01

              2           0.509175E+00    -0.756320E+01    0.403869E+01     0.480092E+01

              2           0.568600E+00    -0.564057E+01    0.310459E+01     0.213989E+01

              2           0.619278E+00    -0.343070E+01    0.202499E+01    -0.280333E+01

              2           0.735503E+00    -0.148734E+01    0.111142E+01    -0.141391E+02

              1           0.125199E+01    -0.411642E-02    0.628054E+00    -0.285704E+02

              2           0.116254E+01    -0.122946E+01    0.119600E+01     0.455526E+02

              4           0.502567E+00    -0.586930E+01    0.318593E+01     0.129142E+02

              4           0.377627E+00    -0.866990E+01    0.452376E+01     0.832296E+01

              4           0.226942E+00    -0.911310E+01    0.467002E+01     0.557240E+01

              4           0.126985E+00    -0.825316E+01    0.419007E+01     0.327513E+01

              4           0.182413E+00    -0.645442E+01    0.331842E+01    -0.716168E+00
```

```
4          0.288081E+00   -0.427647E+01    0.228227E+01   -0.800506E+01

4          0.495661E+00   -0.228644E+01    0.139105E+01   -0.227482E+02

2          0.974702E+00   -0.122508E+01    0.109989E+01   -0.474216E+02

2          0.168745E+01   -0.171185E+01    0.169965E+01    0.432610E+02

4         -0.395466E+00   -0.620562E+01    0.290508E+01    0.166426E+02

4         -0.908875E+00   -0.943623E+01    0.426368E+01    0.798250E+01

4         -0.924320E+00   -0.100962E+02    0.458592E+01    0.344058E+01

4         -0.914574E+00   -0.896776E+01    0.402659E+01    0.470804E+00

4         -0.608510E+00   -0.748762E+01    0.343955E+01   -0.287233E+01

4         -0.811586E-01   -0.522623E+01    0.257254E+01   -0.110602E+02

4          0.588411E+00   -0.298434E+01    0.178638E+01   -0.249124E+02

2          0.150138E+01   -0.135872E+01    0.143005E+01   -0.449523E+02

2          0.164313E+00   -0.248567E+00    0.206440E+00    0.526704E+02

4         -0.295863E+01   -0.693211E+01    0.198674E+01    0.688923E+01

4         -0.421925E+01   -0.105895E+02    0.318063E+01    0.367225E+01

4         -0.410281E+01   -0.116885E+02    0.379283E+01    0.228834E+00

4         -0.293585E+01   -0.954280E+01    0.330347E+01   -0.330200E+01

4         -0.243978E+01   -0.870897E+01    0.313460E+01   -0.595912E+01

4         -0.126594E+01   -0.618407E+01    0.245906E+01   -0.133459E+02

4          0.174997E+00   -0.348868E+01    0.183184E+01   -0.270213E+02

2          0.162351E+01   -0.161569E+01    0.161960E+01   -0.452945E+02

2          0.135606E+01   -0.125626E+01    0.130616E+01   -0.461249E+02

4         -0.201699E+01   -0.636691E+01    0.217496E+01   -0.703950E+01

4         -0.371546E+01   -0.105597E+02    0.342214E+01    0.136965E+01

4         -0.422864E+01   -0.118934E+02    0.383236E+01    0.242414E+01

4         -0.376627E+01   -0.103074E+02    0.327057E+01   -0.695013E+00

4         -0.296351E+01   -0.864790E+01    0.284220E+01   -0.388926E+01

4         -0.198055E+01   -0.670112E+01    0.236029E+01   -0.815069E+01

4         -0.420614E+00   -0.356196E+01    0.157067E+01   -0.244467E+02
```

```
 2          0.140617E+01   -0.141997E+01    0.141307E+01   -0.455914E+02

 2          0.208901E+01   -0.198578E+01    0.203739E+01   -0.459832E+02

 4         -0.120304E+01   -0.602767E+01    0.241232E+01   -0.294407E+02

 4         -0.363555E+01   -0.101225E+02    0.324348E+01   -0.565129E+01

 4         -0.461190E+01   -0.117610E+02    0.357455E+01    0.845193E+00

 4         -0.429291E+01   -0.109014E+02    0.330423E+01    0.241206E+01

 4         -0.325693E+01   -0.849245E+01    0.261776E+01   -0.165708E+00

 4         -0.270676E+01   -0.726017E+01    0.227670E+01   -0.339362E+01

 4         -0.112403E+01   -0.338322E+01    0.112960E+01   -0.160103E+02

 2          0.848903E+00   -0.941884E+00    0.895393E+00   -0.464664E+02

 2          0.212414E+01   -0.187912E+01    0.200163E+01   -0.456515E+02

 4          0.451766E+00   -0.468235E+01    0.256706E+01   -0.189869E+02

 4         -0.687199E+00   -0.804400E+01    0.367840E+01   -0.363793E+01

 4         -0.142582E+01   -0.101885E+02    0.438134E+01    0.417306E+01

 4         -0.174295E+01   -0.103200E+02    0.428854E+01    0.766317E+01

 4         -0.164245E+01   -0.881564E+01    0.358660E+01    0.676601E+01

 4         -0.119085E+01   -0.682792E+01    0.281854E+01    0.434723E+01

 4         -0.771359E+00   -0.347883E+01    0.135373E+01    0.938909E+00

 2          0.225273E+00   -0.879910E-01    0.156632E+00   -0.443486E+02

 2          0.125557E+01   -0.127696E+01    0.126627E+01   -0.463212E+02

 4          0.504257E+00   -0.323648E+01    0.187037E+01   -0.171203E+02

 4          0.217426E+00   -0.630174E+01    0.325958E+01   -0.195370E+01

 4          0.351920E-01   -0.880502E+01    0.442011E+01    0.498789E+01

 4         -0.127872E+00   -0.978867E+01    0.483040E+01    0.812018E+01

 4         -0.207855E+00   -0.913800E+01    0.446507E+01    0.855166E+01

 4         -0.104914E+00   -0.716631E+01    0.353070E+01    0.619645E+01

 4         -0.147884E-01   -0.410275E+01    0.204398E+01    0.104484E+01

 2          0.424473E+00   -0.686508E+00    0.555490E+00   -0.553066E+02

 1          0.114590E+01   -0.222828E+00    0.684364E+00   -0.420617E+02
```

```
  2          0.699677E+00   -0.212557E+01    0.141263E+01   -0.967891E+01

  2          0.574027E+00   -0.500493E+01    0.278948E+01    0.139118E+01

  2          0.445091E+00   -0.773783E+01    0.409246E+01    0.616867E+01

  2          0.345125E+00   -0.933681E+01    0.484097E+01    0.833424E+01

  2          0.327960E+00   -0.936569E+01    0.484683E+01    0.851708E+01

  2          0.440907E+00   -0.792587E+01    0.418339E+01    0.655736E+01

  2          0.796842E+00   -0.529800E+01    0.304742E+01    0.538925E+00

  1          0.172488E+01   -0.403484E+00    0.106418E+01   -0.186556E+02

I-HOMSG, Message number 08058043
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APPENDIX C

CONTOUR PLOTS

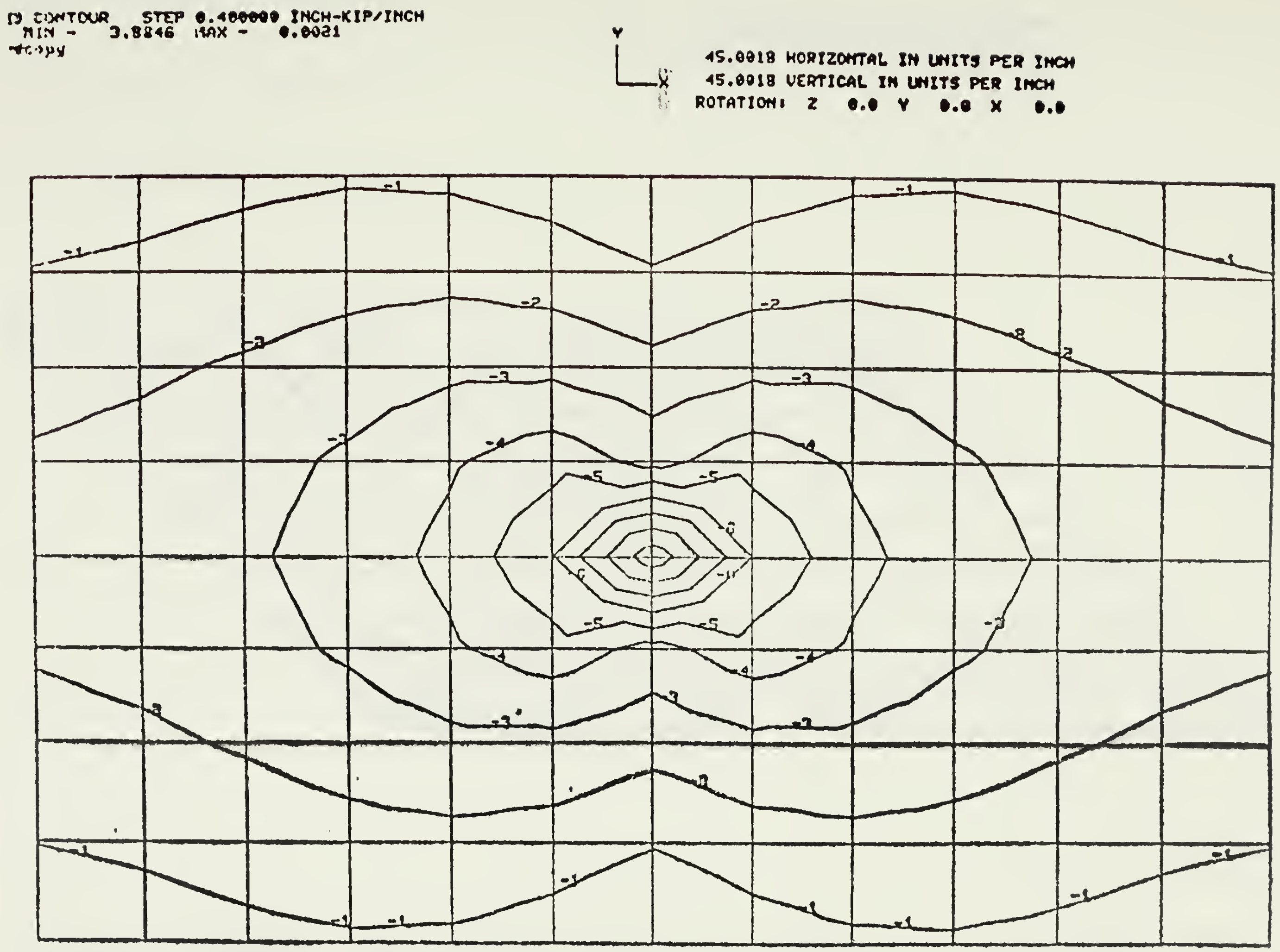
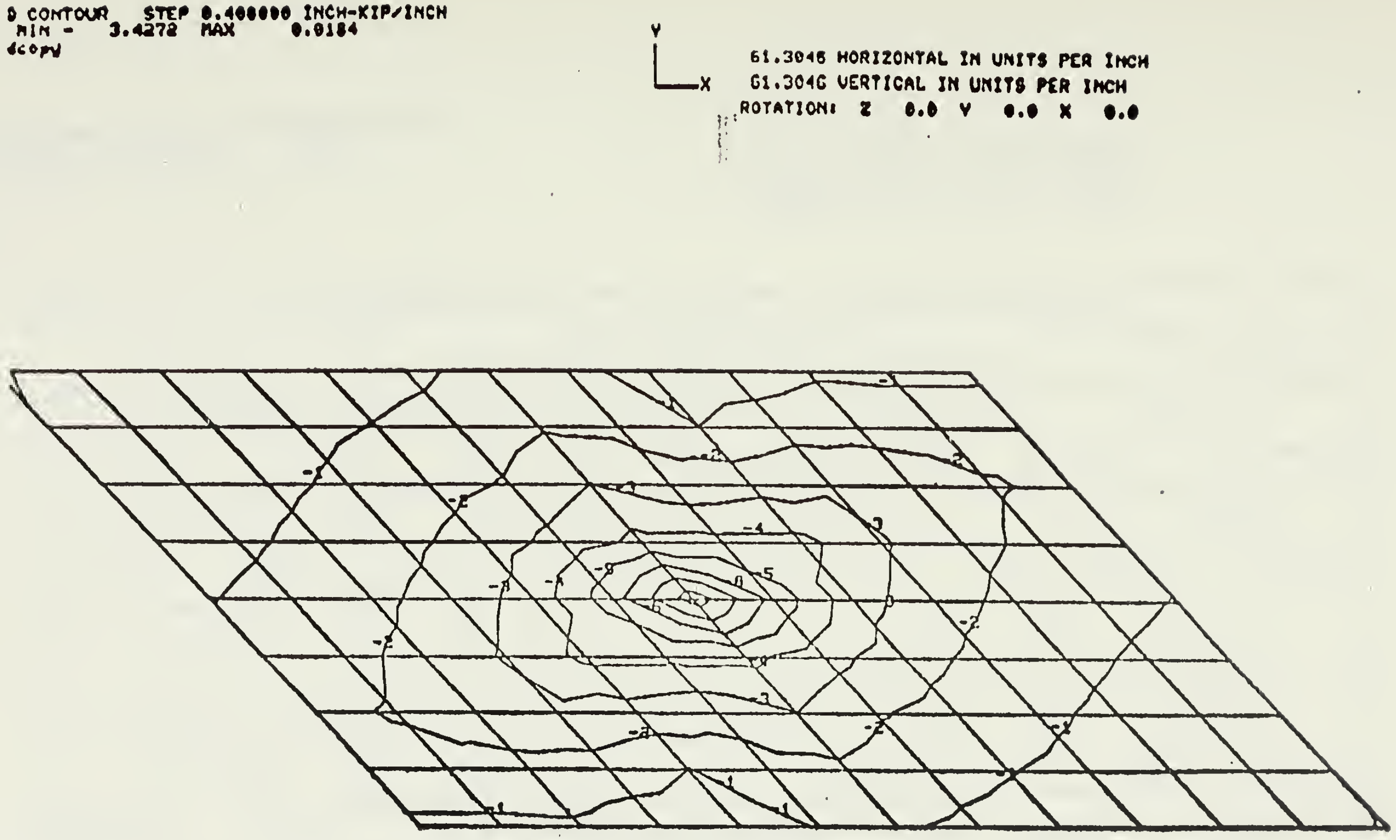


FIGURE C.1 CONTOUR: MAJOR PRINCIPAL MOMENT FOR CENTRAL 10 KIP LOAD, SKEW = 0°



```
0 CONTOUR   STEP 0.400000 INCH-KIP/INCH
 MIN -   3.4272  MAX     0.0184
dcopy
```

```
        61.3046 HORIZONTAL IN UNITS PER INCH
        61.3046 VERTICAL IN UNITS PER INCH
       ROTATION: Z   0.0  Y   0.0  X   0.0
```

FIGURE C.2 CONTOUR: MAJOR PRINCIPAL MOMENT FOR CENTRAL 10 KIP LOAD, SKEW = 40°

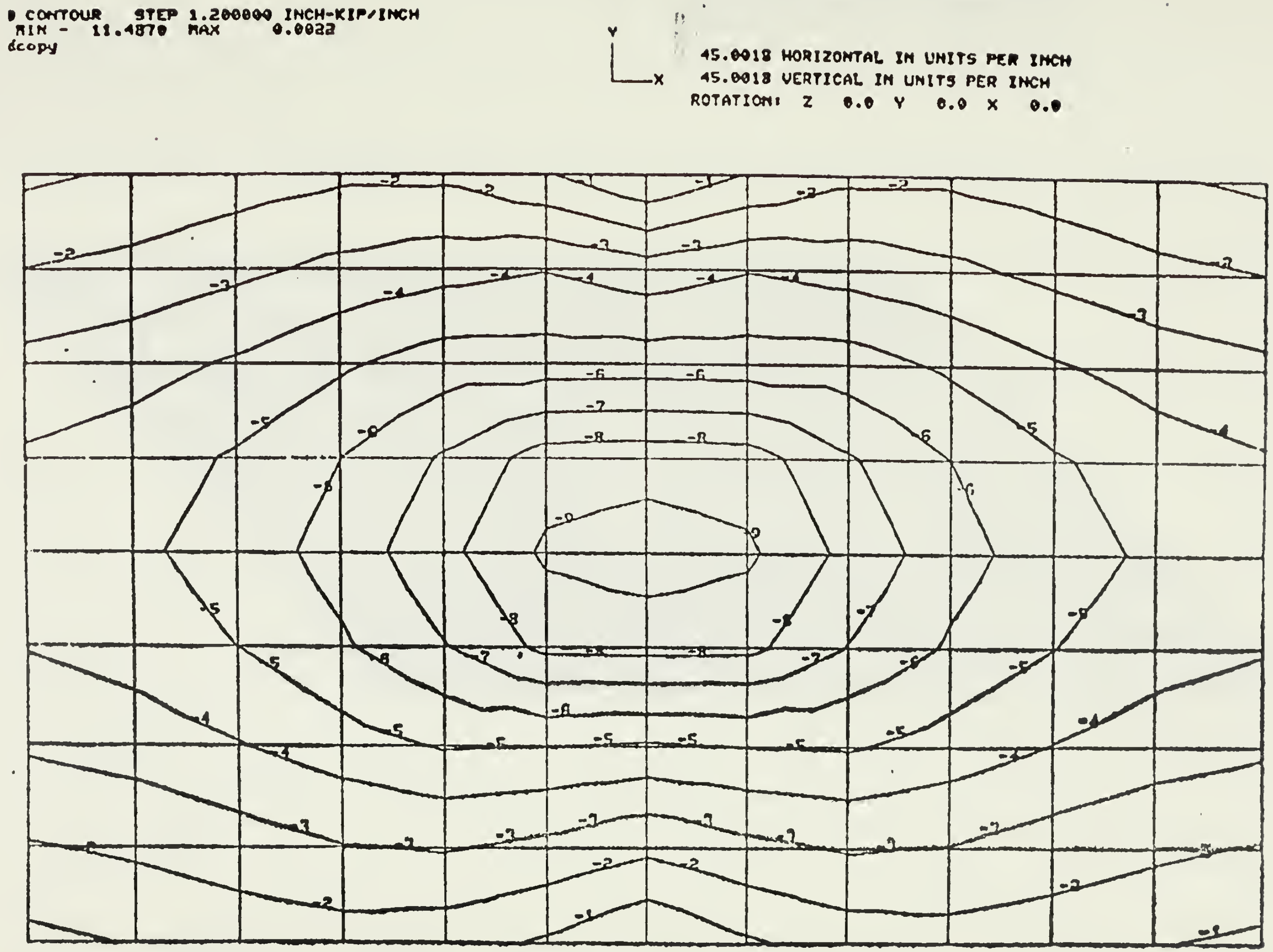
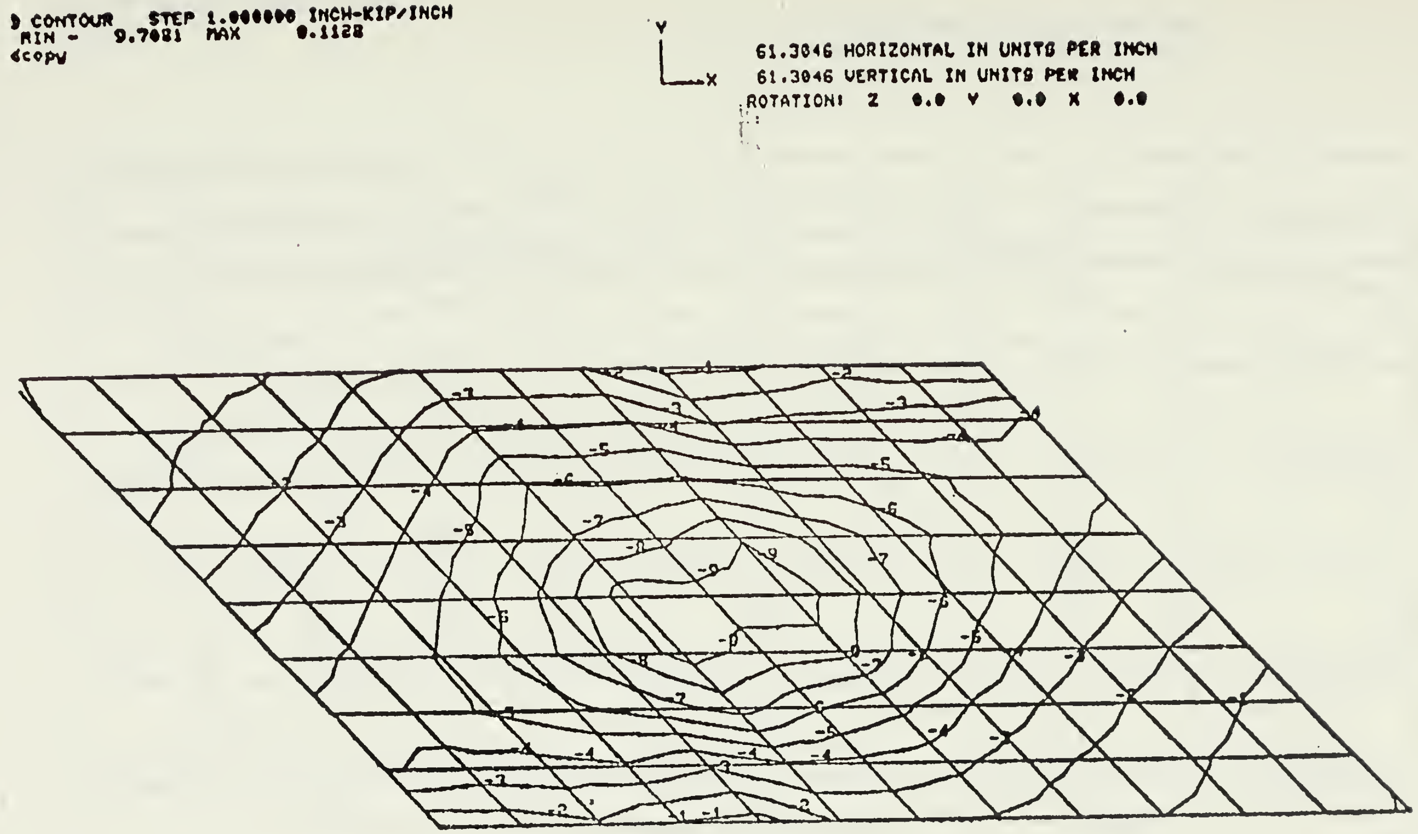


FIGURE C.3 CONTOUR: MAJOR PRINCIPAL MOMENT FOR PEAK SU-4 CENTER LOAD, SKEW = 0°



```
) CONTOUR   STEP 1.000000 INCH-KIP/INCH
 MIN -   9.7081  MAX     0.1128
<copy
```

```
 61.3046 HORIZONTAL IN UNITS PER INCH
 61.3046 VERTICAL IN UNITS PER INCH
ROTATION:  Z   0.0  Y   0.0  X   0.0
```

FIGURE C.4 CONTOUR: MAJOR PRINCIPAL MOMENT FOR PEAK SU-4 CENTER LOAD, SKEW = 40°

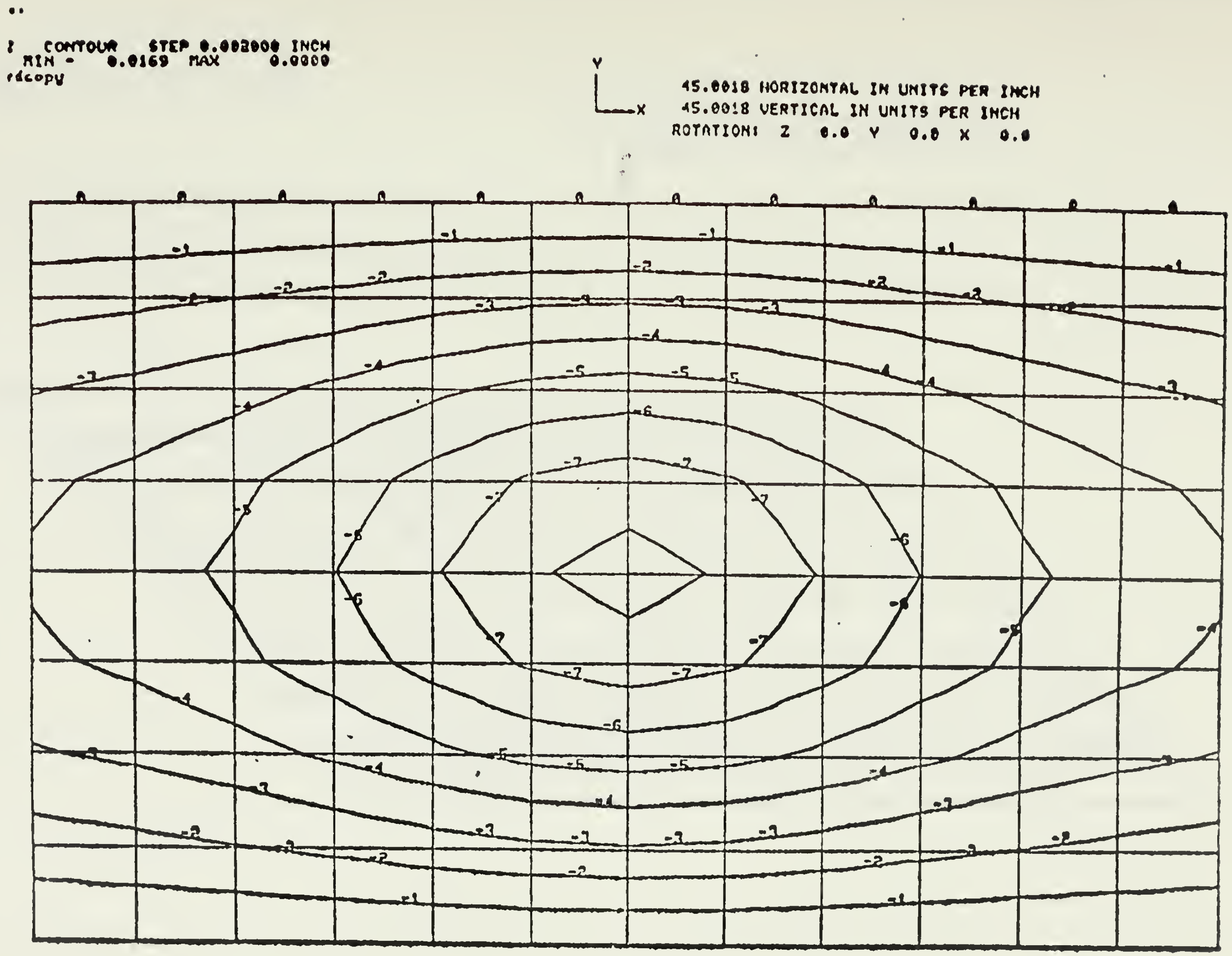


FIGURE C.5 CONTOUR: Z DISPLACEMENT FOR CENTRAL 10 KIP LOAD, SKEW = 0°

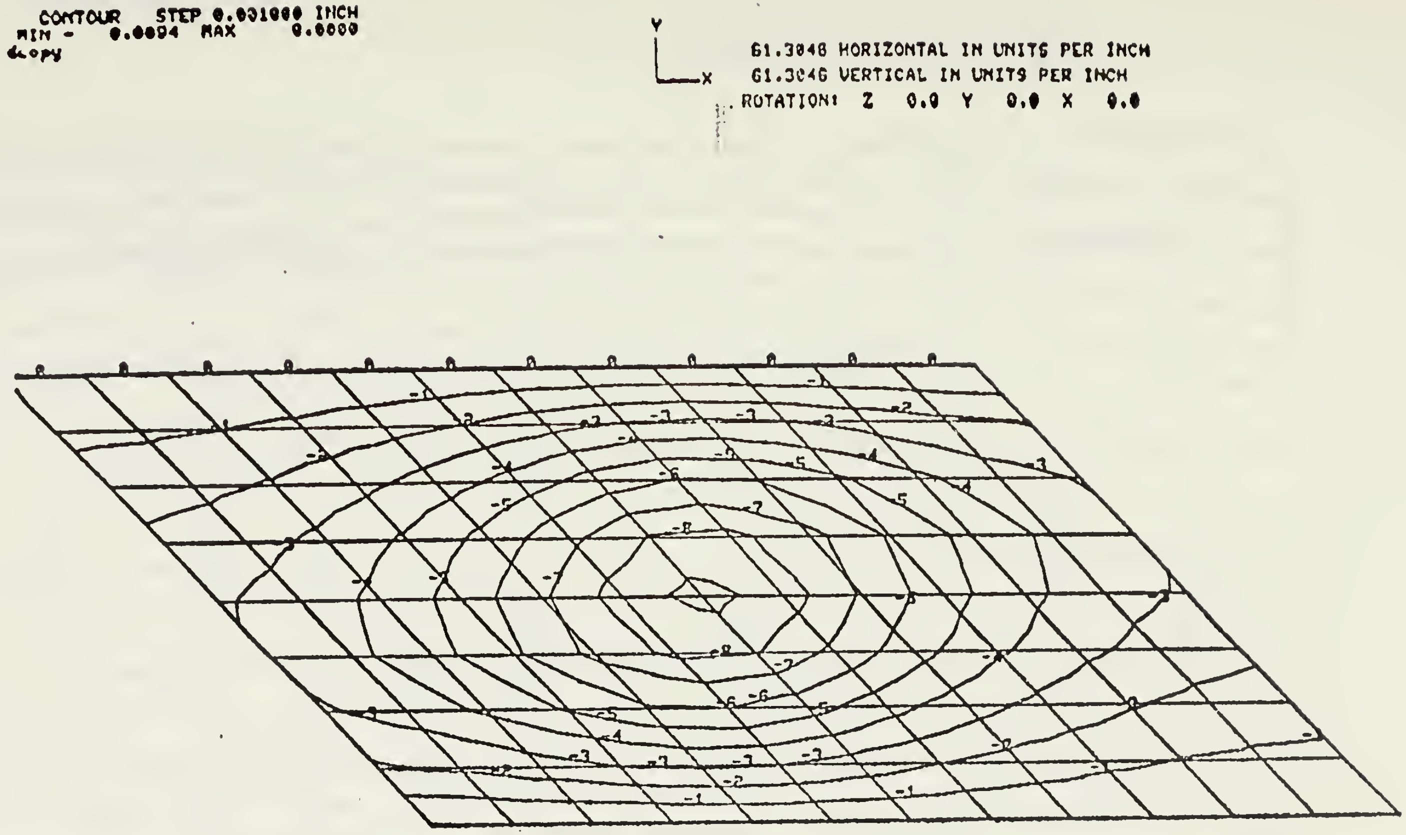


FIGURE C.6 CONTOUR: Z DISPLACEMENT FOR CENTRAL 10 KIP LOAD, SKEW = 40°

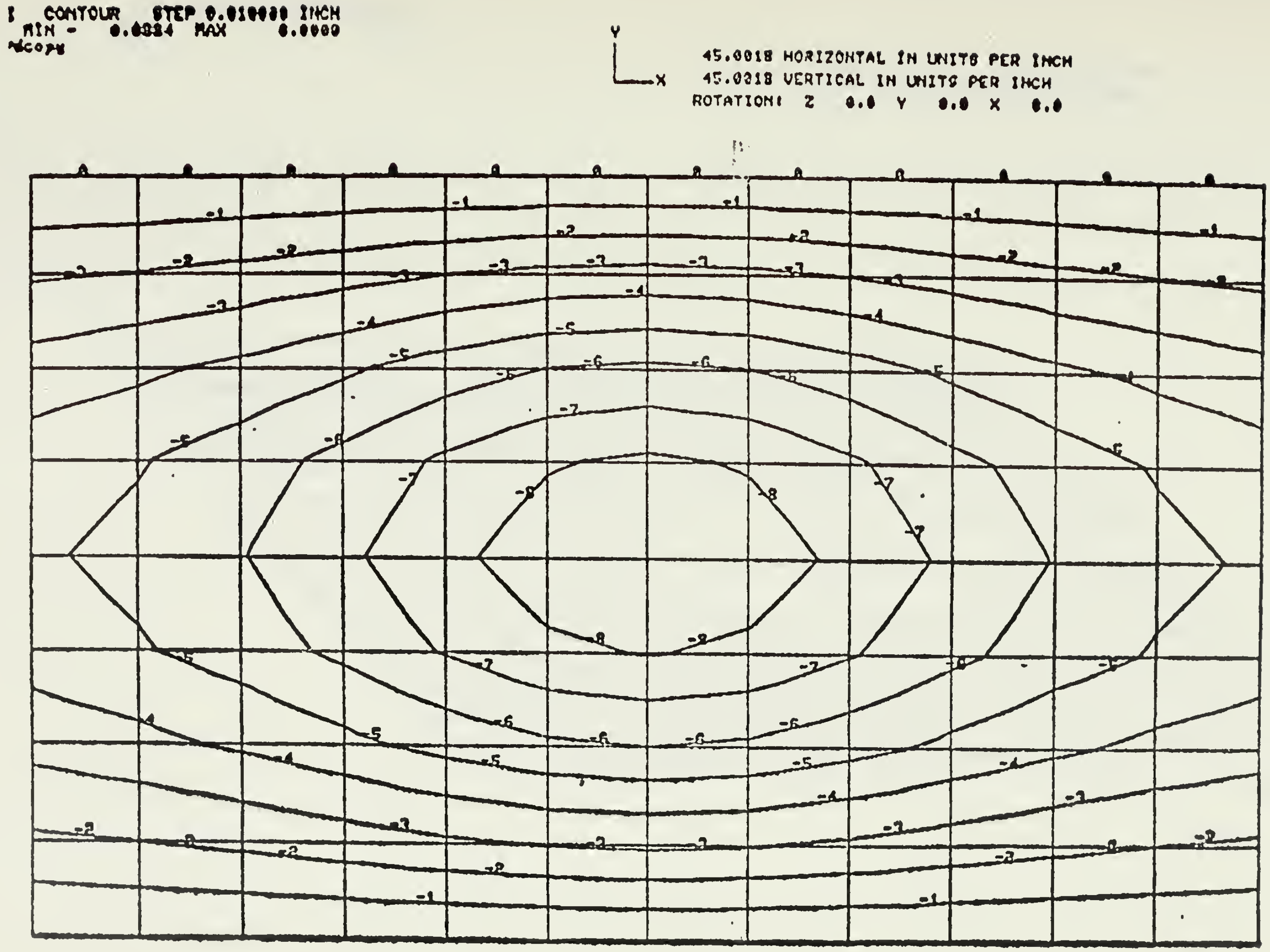


FIGURE C.7 CONTOUR: Z DISPLACEMENT FOR PEAK SU-4 CENTER LOAD, SKEW = 0°

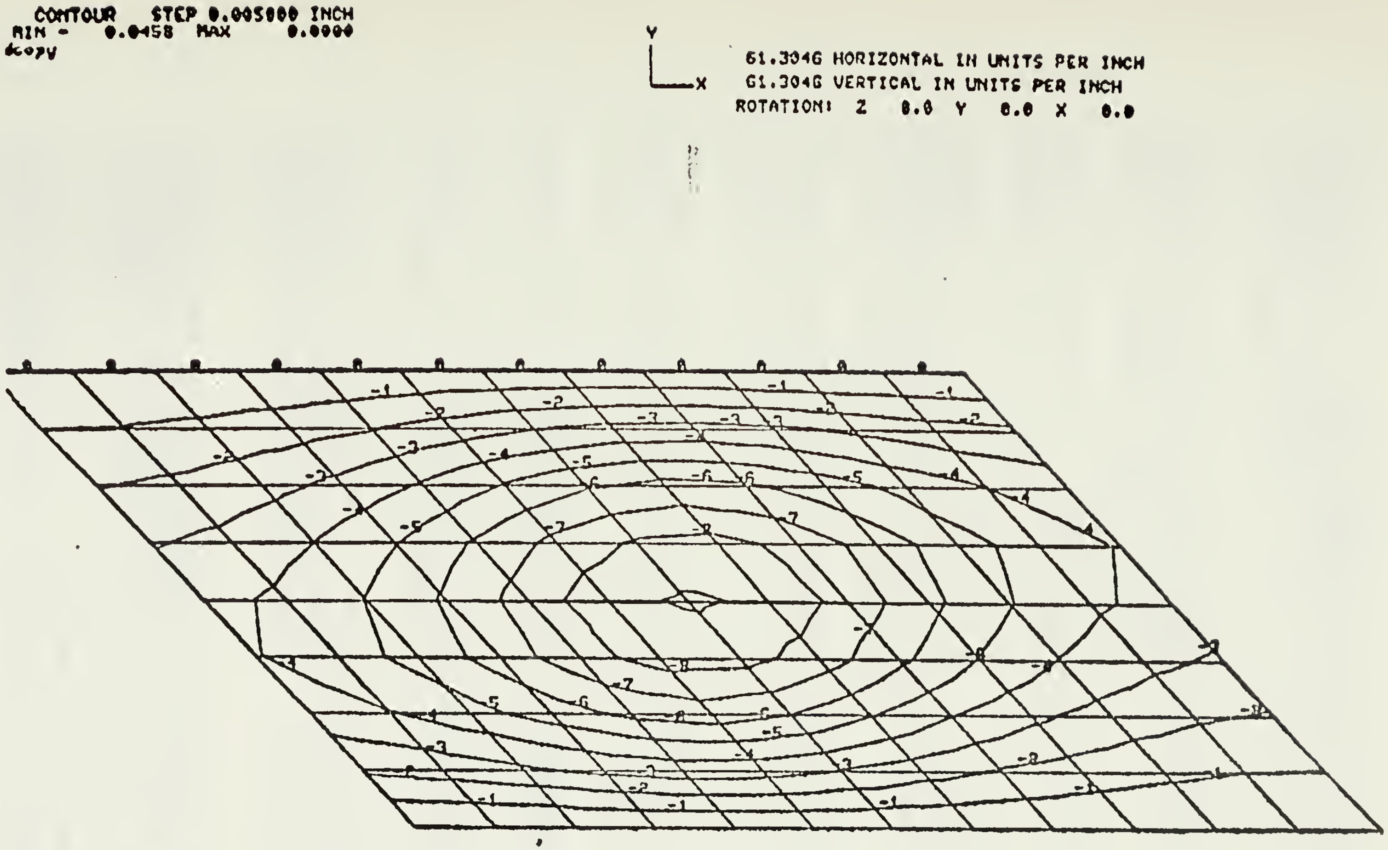


FIGURE C.8 CONTOUR: Z DISPLACEMENT FOR PEAK SU-4 CENTER LOAD, SKEW = 40^0

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